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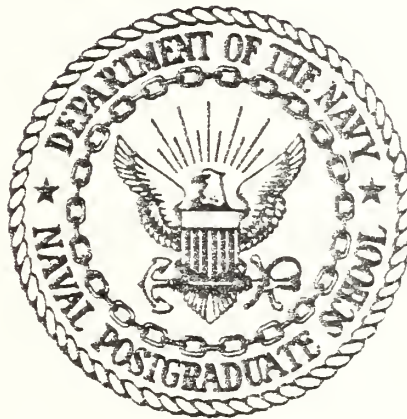






# NAVAL POSTGRADUATE SCHOOL

## Monterey, California



# THESIS

ANALYSIS OF THE HISTORICAL RELATIONSHIP  
BETWEEN CURRENT NAVY RDT&E AND  
FUTURE INVESTMENT IN PROCUREMENT

by

Edward Charles Long, III

December 1978

Thesis Co-Advisors:

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## ABSTRACT (Cont'd)

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Eight separate models are developed, and analysis of results indicates the existence of a predictive relationship. However, there are also indications that the basic relationship may have changed during the period under study. The relative inaccuracy of forecasting methods when earlier data are ignored makes the usefulness of these procedures to those who shape future Navy budgets difficult to determine.



Analysis of the Historical Relationship  
Between Current Navy RDT&E and  
Future Investment in Procurement

by

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Submitted in partial fulfillment of the  
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MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL  
December 1978





ABSTRACT

In partial response to a memorandum for the Superintendent, Naval Postgraduate School, from the Director of the Fiscal Management Division, Office of the Chief of Naval Operations (Serial 922E21/587526 dated 24 April 1978), this thesis attempts to analyze the historical relationship between the Navy's investment in current RDT&E and future investment in procurement. Utilizing data from fiscal years 1962 through 1979 and single equation econometric forecasting techniques, linear models predicting procurement one to four years in advance based on current RDT&E are developed. From time-series data, with the models adjusted for serial correlation of the error terms, ex post forecasts and confidence interval estimations are used to evaluate the extent and usefulness of the predictive relationships discovered.

Eight separate models are developed, and analysis of results indicates the existence of a predictive relationship. However, there are also indications that the basic relationship may have changed during the period under study. The relative inaccuracy of forecasting methods when earlier data are ignored makes the usefulness of these procedures to those who shape future Navy budgets difficult to determine.



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## I. INTRODUCTION

The analysis to be conducted in this thesis was originally proposed by a memorandum from the Director of the Fiscal Management Division, Office of the Chief of Naval Operations, to the Superintendent of the Naval Postgraduate School.<sup>1</sup> Appendix A contains a copy of that correspondence, which expressed concern that more and more promising new weapons programs were being terminated because their estimated procurement costs made them unaffordable. At the same time, the Department of Defense was continuing to increase its research and development efforts. For example, the fiscal year (FY) 1979 Navy Research, Development, Test, and Evaluation (RDT&E,N) appropriation request provided a real program growth of about six percent over the FY 1978 level. The memorandum implied that the increasing complexity and costs of modern systems, at least in part, resulted from earlier research and development effort; and the memorandum expressed an interest in developing, if possible, a predictive model.

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<sup>1</sup>Although the correspondence is officially from the Office of the Chief of Naval Operations (OPNAV) only, its author and most of his subordinates also hold positions in the Office of the Navy Comptroller (NAVCOMPT) under the Secretary of the Navy. To avoid confusion, future references to this correspondence, the analysis or the persons who conducted it will use the modifier "OPNAV/NAVCOMPT".



Specifically, based upon the current investment in research and development, can future procurement requirements be predicted? The OPNAV/NAVCOMPT staff conducted a preliminary study in pursuit of this question, and a discussion of their analysis follows.

#### A. THE OPNAV/NAVCOMPT ANALYSIS

The analysis conducted by the OPNAV/NAVCOMPT staff was limited to eighteen individual development/procurement programs included in the FY 1979 budget submission. These programs were all in the engineering development stage and had progressed to the point of having budget quality estimates of both total research and development and procurement costs through the program years (the four years beyond the budget year) [Refs. 4 and 5]. For each of these programs a ratio of total procurement costs to total research and development costs was calculated. This ratio was then adjusted or weighted by the program's fraction of the FY 1979 RDT&E,N sample.<sup>2</sup> The sum of these individual weighted factors then equated to the relationship between research and development and procurement costs: for every dollar of RDT&E,N, the Navy could expect to spend approximately four dollars procuring the associated weapons systems.

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<sup>2</sup>Weighted Factor = Procurement to RDT&E,N Ratio x  
[Program FY 79 RDT&E,N ÷ Total Sample RDT&E,N].





The limitations of such a study are more or less obvious. The study addresses only a single year's data, and much of those are estimated. There exists a wide variance among the calculated procurement to research and development ratios (from a high of 33.2 to a low of 0.4). Thus, what may be true for this sample may not necessarily be true for a different one. The amount of RDT&E,N money included in the study represented only 25 percent of the total RDT&E,N budget request. Finally, the ratios of procurement to research and development were apparently calculated without adjusting costs to consistent or constant dollar figures. The study mixed dollars of past, present, and projected future purchasing power. Adjusting for this difference would not be an easy task in light of the way in which the data were presented.



## II. AN EXPANDED STUDY

This thesis will expand the study of the relationship between procurement and research and development costs. Investigation of possible methods of conducting this expanded analysis produced two general alternatives:

### A. ALTERNATIVE METHODS

#### 1. The Micro Approach

This alternative would proceed in an effort to identify individual programs for which RDT&E,N and procurement investments had been made. These data could then be aggregated to provide a basis for estimating the overall relationship of procurement to research and development in much the same manner as the OPNAV/NAVCOMPT analysis. In addition, individual programs could then be categorized in such a manner as to study particular types of systems (e.g. high performance aircraft or surface radar systems).

#### 2. The Macro Approach

This alternative would use aggregate historical budget data rather than figures for individual programs. The relationship of total RDT&E,N to a total of the Navy's procurement accounts could be studied, as well as relationships by program budget activity or Department of Defense (DOD) program category (e.g. RDT&E,N for aircraft and missiles versus procurement of aircraft and missiles).



The macro approach was chosen for several reasons. First, pursuit of the micro approach with the thought of logically connecting each dollar spent in RDT&E,N to an item of current or future procurement would have fallen well short of that goal. There is a significant portion of the total RDT&E,N budget, such as basic research and management and support, which could never be "applied" to a particular procurement action in other than an arbitrary manner. Secondly, what historical data we now have concerning the RDT&E,N and procurement monies spent on specific programs are made available mainly through Selected Acquisition Reports (SAR's) which are submitted by the Navy to the Department of Defense. These SAR's provide a means of tracking costs on a regular basis. Unfortunately, these reports cover only major programs (over \$75 million RDT&E,N and/or \$300 million procurement) and go back only as far as 1970 [Refs. 3 and 6]. Finally, an attempt to trace historical RDT&E,N detailed program element data to procurement data for the major programs or for the myriad of smaller programs would have resulted in an excessively time-consuming data extraction process and, in the end, would still have left much of the RDT&E,N investment unaccounted for.

## B. ASSUMPTIONS AND DEFINITIONS

The most basic assumption underlying any financial analysis is that human behavior can be reasonably and





accurately represented by a dollar figure. More specifically in regard to this study, human behavior which we might define as the "level of effort" in research and development and the "level of effort" in procurement are assumed to be susceptible to representation by dollar figures. But which dollar figure among the many available in the DOD budgetary process best represents these levels of effort? Terms like authorization, appropriation, outlay, expenditure, budget authority, new obligational authority, total obligational authority, budget activity, program, total program, DOD program category, reimbursements, reimbursable, budget plan, and obligation are not easily, widely, or fully understood, in spite of the many text book definitions available.

Appendix B is a glossary which will provide the reader with definitions of terms as they are used in this analysis, but additional explanation of this thesis' answer to the question posed above (i.e. which dollar figure is best) is in order. Table 1 presents a page from The Budget of the United States Government, 1970 - Appendix and will serve as an example of the complexity (and in some cases inconsistency) of terminology and as support for the answer at which we will arrive.

Table 1 presents the schedule of program costs and financing for the Navy's procurement of aircraft and missiles (PAMN) appropriation account for FY 1970. This



TABLE I

## PROCUREMENT OF AIRCRAFT AND MISSILES, NAVY—Continued

Program and Financing (in thousands of dollars)

Identification code 07-15-1505-0-1-051	Budget plan (amounts for procurement actions programmed)			Obligations		
	1968 actual	1969 estimate	1970 estimate	1968 actual	1969 estimate	1970 estimate
<b>Program by activities:</b>						
<b>Direct:</b>						
1. Combat aircraft.....	1,535,275	1,503,340	1,494,100	1,683,371	1,484,600	1,570,300
2. Airlift aircraft.....	-----	15,039	36,800	-----	9,300	27,700
3. Trainer aircraft.....	73,798	33,415	110,200	81,322	83,200	104,300
4. Other aircraft.....	4,265	-----	8,600	4,144	11,000	10,600
5. Modification of aircraft.....	441,062	401,251	325,900	469,680	405,200	361,900
6. Aircraft spares and repair parts.....	606,066	373,626	584,200	632,909	390,000	533,400
7. Aircraft support equipment and facilities.....	99,301	101,500	99,100	96,877	88,100	97,300
8. Ballistic missiles.....	175,039	384,680	517,900	99,696	330,500	485,000
9. Other missiles.....	329,203	326,941	258,000	335,239	525,400	232,400
10. Modification of missiles.....	20,820	19,345	27,000	21,275	15,400	19,900
11. Missile spares and repair parts.....	25,743	21,971	38,900	13,275	20,800	27,000
12. Missile support equipment and facilities.....	29,966	16,779	23,300	20,023	16,500	22,600
Total direct.....	3,340,538	3,248,387	3,524,000	3,457,311	3,180,600	3,512,400
<b>Reimbursable:</b>						
7. Aircraft support equipment and facilities.....	29,281	26,000	26,000	14,585	15,000	15,000
12. Missile support equipment and facilities.....	17,240	21,000	21,000	19,857	20,000	20,000
Total reimbursable.....	47,021	47,000	47,000	34,442	35,000	35,000
10 Total.....	3,387,559	3,295,387	3,571,000	3,492,253	3,215,600	3,547,400
<b>Financing:</b>						
<b>Receipts and reimbursements from:</b>						
11 Federal funds.....	-35,310	-35,300	-35,300	-19,233	-35,300	-35,300
13 Trust funds.....	-22,317	-22,300	-22,300	-19,569	-22,300	-22,300
14 Non-Federal sources.....	-4,394	-4,400	-4,400	-3,991	-4,400	-4,400
21 Unobligated balance available, start of year:	-----	-----	-----	-----	-----	-----
For completion of prior year budget plans.....	-----	-----	-----	-1,572,837	-1,212,814	-1,202,514
Available to finance new budget plans.....	-----	-159,000	-----	-----	-159,000	-----
Reprogramming from prior year budget plans.....	-243,638	-40,087	-75,300	-----	-----	-----
22 Unobligated balance transferred from other accounts.....	-----	-410,000	-25,000	-7,517	-410,000	-25,000
24 Unobligated balance available, end of year:	-----	-----	-----	-----	-----	-----
For completion of prior year budget plans.....	-----	-----	-----	1,212,814	1,202,514	1,151,114
Available to finance subsequent year budget plans.....	159,000	-----	-----	159,000	-----	-----
Budget authority.....	3,240,900	2,574,300	3,409,000	3,240,900	2,574,300	3,409,000
<b>Budget authority:</b>						
40 Appropriation.....	2,939,100	2,574,300	3,409,000	2,939,100	2,574,300	3,409,000
42 Transferred from other accounts.....	301,800	-----	-----	301,800	-----	-----
43 Appropriation (adjusted).....	3,240,900	2,574,300	3,409,000	3,240,900	2,574,300	3,409,000
<b>Relation of obligations to outlays:</b>						
71 Obligations incurred, net.....	-----	-----	-----	3,449,440	3,153,600	3,485,400
72 Obligated balance, start of year.....	-----	-----	-----	3,764,367	3,571,799	3,120,399
74 Obligated balance, end of year.....	-----	-----	-----	-3,571,799	-3,120,399	-3,265,799
90 Outlays.....	-----	-----	-----	3,642,008	3,605,000	3,340,000

† Reimbursements from non-Federal sources are derived principally from cash sales to foreign governments of other aircraft components, and spares and repair parts (22 U.S.C. 2315).



schedule provides actual figures for the previous year (1968) and estimates for the current year (1969) and budget year (1970). It is presented in three main parts: (1) the program-by-activities section, (2) the financing section, and (3) the section on relation of obligations to outlays.

The program-by-activities section presents the results of the executive branch's programming function in terms of financial requirements by budget activity. This classification by budget activity is not consistent throughout the budget for each appropriation nor is it consistent with the DOD classification by program category [Refs. 2, 5, and 7]. The former characteristic reflects the fact that each appropriation account is divided among several budget activities and that these vary from appropriation to appropriation. The latter indicates that DOD program category classification (e.g. strategic forces, general purpose forces, etc.) has an orientation entirely different from the appropriation's program-by-activities section. This necessitates the function known as "crosswalking", or being able to shift from budget appropriation to DOD program and back again [Refs. 1 and 4].

The financing section shows the sources of funds (budget authority, receipts and reimbursements, unobligated balances available and amounts transferred in, etc.) which will be used to support the financial requirements as determined above.



The relation-of-obligation-to-outlays section shows obligations net of offsetting collections at the start and end of each year and presents the actual net cash outflow as a result of the programming and budgeting activity conducted in connection with this appropriation account.

The appropriation (adjusted) section is included when required for the year prior. It merely shows what portion of the appropriation for that year was actually transferred from other accounts.

Selection of that dollar figure which would best represent the level of effort is based upon the definitions of the terms programming and budgeting as they are used in the context of the Federal financial management process. Programming is defined as the process of translating planned military force requirements into time-phased manpower and material resource requirements. Budgeting is defined as the process of translating approved resource requirements (manpower and material) into time-phased financial requirements [Ref. 5]. Where these processes interface, that is, where time-phased manpower and material resource requirements are first stated in terms of financial requirements appears to be the point at which to determine the best financial representative of "level of effort". The dollar figure at this point (refer to Table 1) is the total direct program figure and represents the financial requirements of each budget activity necessary to support approved programs.





This total is the equivalent of the more commonly-used term, total obligational authority (TOA). However, it is not simply new obligational authority plus unobligated balances, which is the most frequently heard definition of TOA [Ref. 1].

For the purposes of this study, the data used will be the total direct program by budget activities for the Navy's Research Development, Test, and Evaluation (RDT&E,N), and the Navy's procurement accounts (PAMN - Procurement of Aircraft and Missiles; WPN - Weapons Procurement; APN - Aircraft Procurement; OPN - Other Procurement; and PMC - Procurement, Marine Corps). These data will be actual historical data in so far as practicable. For fiscal years 1978 and 1979 the data will be estimates only [Ref. 8].

### C. HYPOTHESIS

The general working hypothesis under which the remainder of this analysis will be conducted is as follows: there exists a predictive relationship between current Navy research and development efforts and future investments in procurement.



### III. THE METHODOLOGY

#### A. THE DATA

As indicated above, data used in this study will be the total direct program figures for the Navy's RDT&E and procurement accounts. These have been taken from the annually published Budget of the United States Government ...Appendix [Ref. 8] and, except for FY 1978 and FY 1979, will be actual figures. That is, the amounts will originate in the budget plan's "actual" column of the program-and-financing section for each appropriation. For example, the figure for the Navy's 1968 PAMN account is obtained from The Budget of the United States Government, 1970 - Appendix. The total direct FY 1968 PAMN program is \$3,340,538,000, as shown in Table 1.

Data were collected for each full fiscal year starting with 1962 and ending with 1979.<sup>3</sup> It was felt that this time span would provide enough data to develop a predictive model if, in fact, such a relationship existed. Of course, the figures contained in the budget documents are in current U.S. dollars, and an adjustment to constant dollars (FY 1979 dollars in this case) was made prior to the conduct of the analysis. Factors for converting current dollars to

---

<sup>3</sup>Data from the transition quarter of 1976, designated 19TQ, were ignored by this study.



constant FY 1979 dollars were obtained for each appropriation account as promulgated by DOD on February 10, 1978. Appendix C contains in tabular form the current dollars, adjusting factors, and constant dollars for all of the quantitative data used in this study.

## B. THE MODEL

The basic principles of econometrics and economic forecasting will be used to determine if there exists a predictive relationship between current efforts in RDT&E and future efforts in procurement. This relationship will be described initially by the classical normal linear regression model:

$$Y_t = a + b X_t + e_t \quad (1)$$

where

$Y$  = the dependent variable,

$X$  = the explanatory variable,

$e$  = a random error term whose values are based upon an underlying probability distribution,

$a$  and  $b$  = regression parameters which are unknown,

$X$  and  $Y$  are observable but  $e$  is not, and

the subscript  $t$  refers to the  $t^{\text{th}}$  observation [Ref. 10].



In this analysis the explanatory variable,  $X$ , will always be the RDT&E,N direct program in the budget year (BY), while the dependent variable will be one or a total of the Navy's procurement direct programs for one or more of the program years. Since these observations are made over time, they are often referred to as "time-series data" [Ref. 10]. Thus, the subscript  $t$  is used rather than the more common  $i$ .

### C. ASSUMPTIONS

In addition to the general form of the model as expressed in equation (1), the classical normal linear regression model must conform to the following basic assumptions.

1. Normality

The error term,  $e_t$ , is normally distributed.

2. Zero Mean

The expected value of the error term,  $E(e_t)$ , is equal to zero.

3. Homoscedasticity

Every disturbance,  $e_t$ , has the same variance,  $S^2$ , whose value is unknown.

4. Nonstochastic  $X$

The explanatory variable,  $X_t$ , is nonstochastic (nonrandom) with values fixed in repeated samples and such that, for any sample size,

$$\frac{1}{n} \sum_{t=1}^n (X_t - \bar{X})^2$$





is a finite number different from zero. ( $\bar{X}$  is the mean value of all  $X_t$ , and  $n$  is the number of data pairs in the sample.)

#### 5. Nonautoregression

The error terms,  $e_t$ , are uncorrelated in a statistical sense [Refs. 10 and 12].

This analysis assumes that the data conform to all of the basic assumptions listed above except the fifth, nonautoregression. This assumption is most often violated by relations estimated from time-series data [Refs. 9 and 10], and the analysis will proceed on the opposite assumption, determine the extent of autoregression or serial correlation present, and make the necessary adjustments to the model.

#### D. PROCEDUREAL DETAILS

For each set of data, certain steps will be taken in the following logical sequence.

##### 1. Ordinary Least Squares (OLS) Regression

The method of least squares will be used to provide estimates of the model's regression parameters  $a$  and  $b$  where

$$a = \frac{\sum Y_t}{n} - \frac{b \sum X_t}{n}$$

and



$$b = \frac{n\sum X_t Y_t - \sum X_t \sum Y_t}{n\sum X_t^2 - (\sum X_t)^2}$$

This procedure in graphic terms results in a straight line which minimizes the sum of the squared deviations of the data points on the graph from the points on the straight line (with distances measured vertically).

## 2. The Hildreth-Lu Procedure

Autoregression of the data's error terms has been assumed. The next step is to determine the extent of first order serial correlation present, if any, by using the Hildreth-Lu procedure [Ref. 12] to estimate a new parameter,  $r$ , which is the correlation coefficient between errors in time period  $t+1$  and errors in time period  $t$ .

In this procedure, a set of values are specified for  $r$ , and for each value of  $r$ , another OLS regression is conducted and error sum of the squares (ESS)<sup>4</sup> calculated on the following equation.

$$Y_t^* = a(1-r) + bX_t^*$$

where

$$Y_t^* = Y_{t+1} - rY_t,$$

---

<sup>4</sup>ESS = The sum of the squared differences between the estimated and observed values of the dependent variable.



and

$$X_t^* = X_{t+1} - rX_t.$$

The procedure selects that value of  $r$  which results in the lowest ESS, guarantees a maximum likelihood estimate of  $r$ , and may be repeated until the desired accuracy is achieved, to the nearest thousandth in this instance.

### 3. Generalized Differencing

By this procedure the original model is changed into one for which the error terms are independent. The result is the transformed equation,

$$Y_t^* = a(1-r) + bX_t^* + v_t, \quad (2)$$

where

$$Y_t^* = Y_{t+1} - rY_t,$$

$$X_t^* = X_{t+1} - rX_t,$$

and

$$v_t = e_{t+1} - re_t$$

are the generalized differences of  $Y_t$ ,  $X_t$ , and  $e_t$ , respectively. The transformed equation (2) has an error process



which is independently distributed with zero mean and constant variance, and an OLS regression applied to it will produce estimates of all the parameters. The intercept of the original model, however, must be calculated from the estimated intercept associated with equation (1) [Ref. 12]. Thus, once the correlation coefficient of the error terms,  $r$ , is known or has been estimated, it is a relatively simple matter to adjust the original model.

#### 4. Forecasting

Having completed the procedure as outlined above, the estimates of  $a(1-r)$ ,  $b$ , and  $r$  as they appear in model (2) have been obtained. These are then substituted into the model along with expressions for the generalized differences of  $Y_t$ ,  $X_t$ , and  $e_t$ :

$$Y_{t+1} - rY_t = a(1-r) + b(X_{t+1} - rX_t) + e_{t+1} - re_t$$

A forecast value of  $Y_{t+1}$ , denoted by  $\hat{Y}_{t+1}$  may then be obtained:

$$\hat{Y}_{t+1} = rY_t + a(1-r) + bX_{t+1} - brX_t \quad (3)$$

The error term,  $v_t = e_{t+1} - re_t$ , has been dropped from equation (3) for reasons of clarity. Without proceeding with mathematical proofs, the variance of the forecast error which will be used to obtain confidence intervals about the point estimate ( $\hat{Y}_{t+1}$ ) is given by





$$S_v^2 = (1-r^2) S_f^2$$

where

$$S_f^2 = S^2 \left[ 1 + \frac{1}{T} + \frac{(X_{t+1} - \bar{X})^2}{(X_t - \bar{X})^2} \right], \quad (4)$$

$$S^2 = \frac{1}{T-2} \sum (Y_t - \bar{Y})^2 \quad (5)$$

and

$T$  = the number of observed pairs in the original data set.

The 95% confidence interval using the Student's t distribution for  $\hat{Y}_{t+1}$  is

$$\hat{Y}_{t+1} - t_{.025;n-2} S_v = Y_{t+1} = \hat{Y}_{t+1} + t_{.025;n-2} S_v \quad (6)$$

where

$$S_v = \text{the standard error of the forecast} \quad (7)$$

$$= S_v^2 = (1-r^2) S_f^2$$

and



$t_{.025;n-2}$  = the value of the t distribution with  $n-2$  degrees of freedom such that 2.5% of the area under the curve lies to the right of that value. Provides the basis for a two-sided hypothesis test at the 95% level of significance [Ref. 11].

From equations (3) and (4), the statistical accuracy of the prediction is dependent upon the size of the sample, the range of experience of the explanatory variable  $X$ , the distance between the new explanatory variable  $X_{t+1}$ , and the average value of all  $X$ ,  $\bar{X}$  [Ref. 12].

## 5. Presentations

For each set of variables the following presentations will be made:

a. A table of observed variables, variables in generalized difference form, and ex post forecasts. Data will be rounded to the nearest million and expressed in FY 1979 dollars.

b. An expression for the OLS regression in the form,  $Y = a + bX$

c. An expression of the new, corrected or adjusted regression in the form  $\hat{Y}_{t+1} = rY_t + a(1-r) + bX_{t+1} - brX_t$

d. A table of data which will include for a range of values of the explanatory variable ( $X_{t+1}$ ), the point estimate of the dependent variable ( $\hat{Y}_{t+1}$ ) from equation (3), the variance of the forecast error ( $S_f^2$ ) from equation (4), the standard error of the forecast ( $S_v$ ) from equation (7), and the width of one side of a 95% confidence interval from equation (6).



e. A graph with procurement ( $Y_t$ ) measured along the ordinate and RDT&E,N ( $X_t$ ) along the abscissa, displaying the data points, the OLS regression line, the adjusted regression line, and 95% confidence bands about the adjusted regression line.

f. A graph of procurement and RDT&E measured along the ordinate versus time measured along the abscissa, displaying observed data, forecasted results (i.e. what the model would have predicted), and 95% confidence bands about the forecasted value. The width of these confidence bands is that of the "next" forecast if the explanatory variable ( $X_{t+1}$ ) were exactly equal to the average of the previous explanatory variables ( $\bar{X}$ ). Thus, it is as narrow as it can be and, for the purposes of presenting pictorially how well the model predicted ex post facto, presents the most rigorous test. In addition, a numerical expression of the goodness of fit over the entire time period,  $R^2$ , is provided.

$$R^2 = \frac{\text{Regression Sum of the Squares (RSS)}}{\text{Total Sum of the Squares (TSS)}}$$

where

TSS = The total variation of the dependent variable. The sum of the squares of the difference between the observed values of  $Y_t$  and the average value of  $Y_t$ ,

and



RSS = The explained variation of the dependent variable. The sum of the squares of the differences between the forecasted or predicted values of  $Y_t$  and the average value of  $Y_t$ .

$R^2$  expresses that fraction of the total variance of the dependent variable which is "explained" by the explanatory variable.





#### IV. THE RESULTS

The results of the analyses will now be presented as described in paragraph II.D.5. The first four analyses will match budget year RDT&E with a single year of total Navy procurement one, two, three, and four years in the future. The fifth analysis matches budget year RDT&E with the aggregate of total Navy procurement in the program years, and the remaining three analyses explore alternatives along similar four-year aggregate procurement totals, again using RDT&E as the explanatory variable.

For each set of variables, denoted by second-order headings (A,B,...,H), the following presentations will be made under corresponding third-order headings: (1) A table of observed variables, variables in generalized difference form and ex post forecasts (more fully explained in paragraph III.D.5.a). (2) An expression for the OLS regression in the form

$$Y = a + bX$$

(cf., paragraph III.D.5.b). (3) An expression for the new regression in the form

$$\hat{Y}_{t+1} = rY_t + a(1-r) + bX_{t+1} - brX_t$$

(cf., paragraph III.D.5.c). (4) A table of data which includes for a range of values of the explanatory variable



$(X_{t+1})$ , the point estimate of the dependent variable ( $\hat{Y}_{t+1}$ ), the variance of the forecast error ( $S_f^2$ ), the standard error of the forecast ( $S_v$ ), and the width of one side of a 95% confidence interval (cf., paragraph III.D.5.d). In addition, two figures, numbered sequentially, will be provided for each set of variables, the first showing pictorially the relationship between Procurement and RDT&E,N, and the second showing the relationship of both over time as well as the model's forecasted results (cf., paragraphs III.D.5.e and II.D.5.f).



A. PROCUREMENT IN BUDGET-YEAR-PLUS-ONE VERSUS RDT&E,N  
IN BUDGET YEAR

1. Observed Variables, Variables in Generalized  
Difference Form ( $r = 0.462$ ), and Ex Post Forecast

FY	X	X*	FY	Y	Y*	$\hat{Y}_{t+1}$
62	3025	-----	63	19628	-----	---
63	3394	1996.45	64	16449	7380.864	16998
64	3473	1904.972	65	14580	6980.562	15794
65	3087	1482.474	66	18687	11951.04	16152
66	3332	1905.806	67	19380	10746.606	16826
67	3961	2421.616	68	15271	6317.44	15655
68	3684	1854.018	69	13822	6766.798	15397
69	4075	2372.992	70	14801	8415.236	13228
70	4011	2128.35	71	13405	6566.938	14387
71	3718	1864.918	72	14510	8316.89	14503
72	3865	2147.284	73	13744	7040.38	14198
73	3841	2055.37	74	12307	5957.272	14110
74	3755	1980.458	75	10879	5193.166	13662
75	3893	2158.19	76	12332	7305.902	13579
76	3991	2192.434	77	14787	9089.616	13061
77	4297	2453.158	78	15122	8290.406	13442
78	4266	2280.786	79	13919	6932.636	14090

2. OLS Regression:  $Y = 31195.8483 - 4.3461 X$

3. Regression Line Adjusted for Serial Correlation:

$$\hat{Y}_{t+1} = rY_t + a(1-r) + bX_{t+1} - brX_t$$

$$\hat{Y}_{t+1} = (.462)(13919) + 13700.9173 - 2.8905X_{t+1} + (2.8905)(.462)(4266)$$

$$\hat{Y}_{t+1} = 25828.35863 - 2.8905 X_{t+1}$$

4. Data Table:

$X_{t+1}$	$\hat{Y}_{t+1}$	$S_f^2$	$S_v$	$t_{.025;n-2}$	$S_v$
1000	22938	15565656.6	3499		7456
2000	20047	8504593.073	2586		5512
3000	17157	4589076.808	1900		4049
3745	15003	3716012.22	1710		3643
4000	14266	3818107.809	1733		3693
5000	11376	6191686.073	2207		4703
6000	8485	11709811.60	3035		6467



FIGURE 1

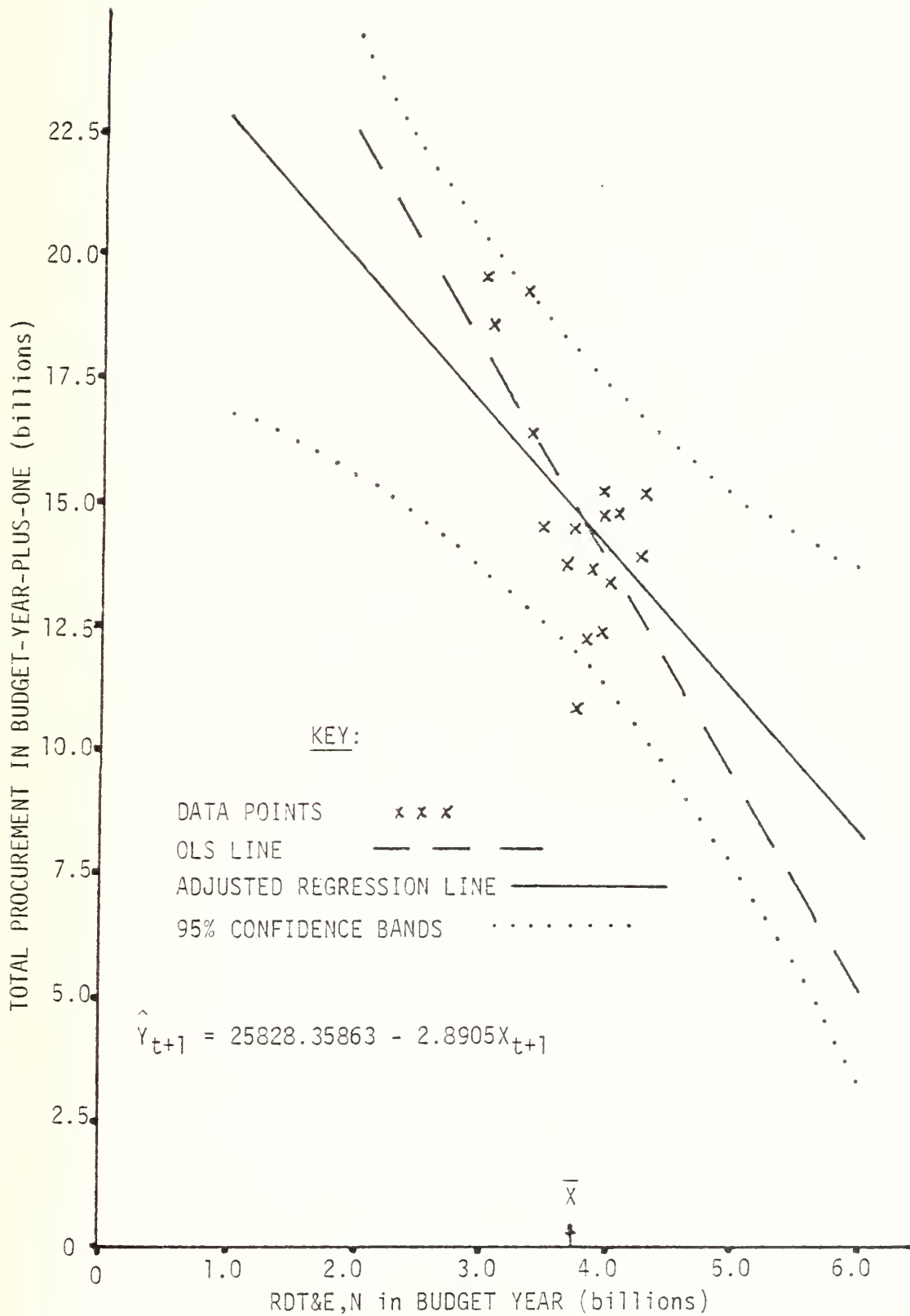
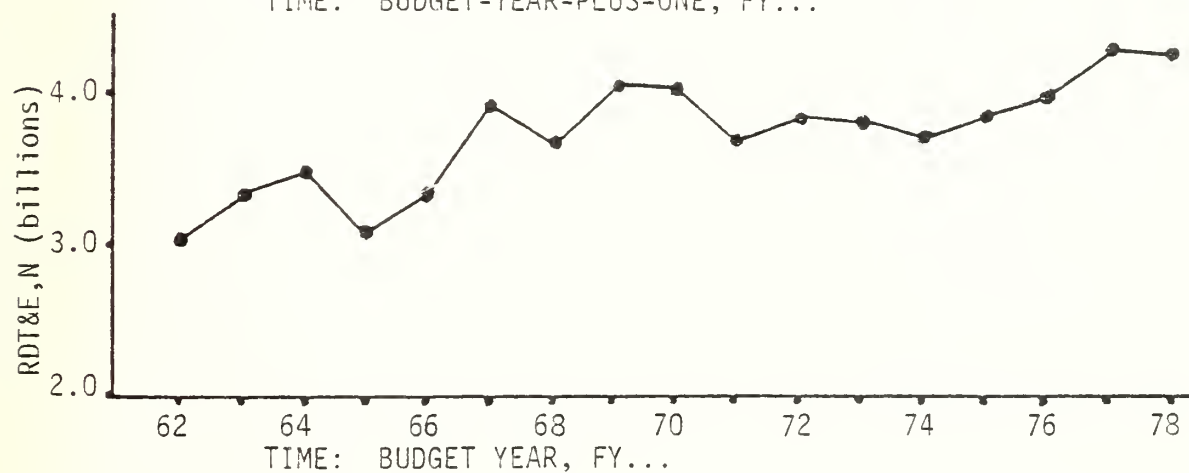
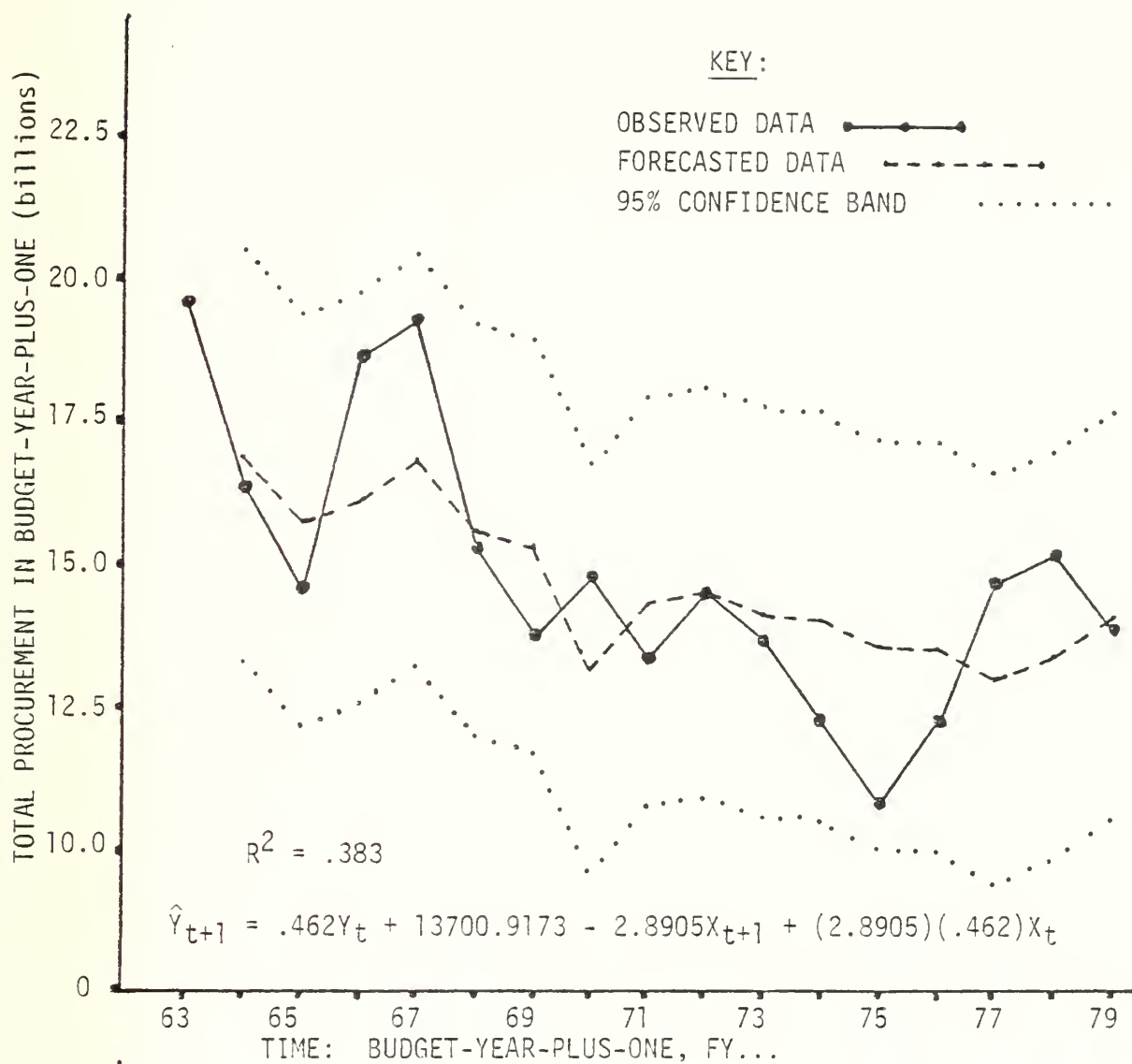






FIGURE 2





B. PROCUREMENT IN BUDGET-YEAR-PLUS-TWO VS. RDT&E,N  
IN BUDGET YEAR

1. Observer Variables, Variables in Generalized  
Difference Form ( $r=.446$ ), and Ex Post Forecast

FY	X	X*	FY	Y	Y*	$\hat{Y}_{t+1}$
62	3025	-----	64	16449	-----	-----
63	3394	2044.85	65	14580	7243.746	15552
64	3473	1959.276	66	18687	12184.32	15010
65	3087	1538.042	67	19380	11045.598	18278
66	3332	1955.198	68	15271	6627.52	17165
67	3961	2474.928	69	13822	7011.134	13560
68	3684	1917.294	70	14801	8636.388	14814
69	4075	2431.936	71	13405	6803.754	13497
70	4011	2193.55	72	14510	8531.37	13687
71	3718	1929.094	73	13744	7272.54	15081
72	3865	2206.772	74	12307	6177.176	13793
73	3841	2117.21	75	10879	5390.078	13458
74	3755	2041.914	76	12332	7479.966	13078
75	3893	2218.27	77	14787	9286.928	13124
76	3991	2254.722	78	15122	8526.998	14095
77	4297	2517.014	79	13919	7174.588	13350

2. OLS Regression:  $Y = 28558.594 - 3.7531 X$

3. Regression Line Adjusted for Serial Correlation:

$$\hat{Y}_{t+1} = rY_t + a(1-r) + bX_{t+1} - brX_t$$

$$\hat{Y}_{t+1} = (.446)(13919) + 15188.2496 - 3.4098X_{t+1} + (3.4098)(.446)(4297)$$

$$\hat{Y}_{t+1} = 27930.87573 - 3.4098X_{t+1}$$

4. Data Table:

$X_{t+1}$	$\hat{Y}_{t+1}$	$S_f^2$	$S_v$	$t_{.025;n-2}$	$S_v$
1000	24521	15188245.69	3488		7482
2000	21111	8056099.446	2540		5449
3000	17701	4147349.016	1823		3910
3713	15270	3328866.905	1633		3503
4000	14292	3461967.396	1665		3571
5000	10882	5999981.585	2192		4702
6000	7472	11761382.58	3070		6585



FIGURE 3

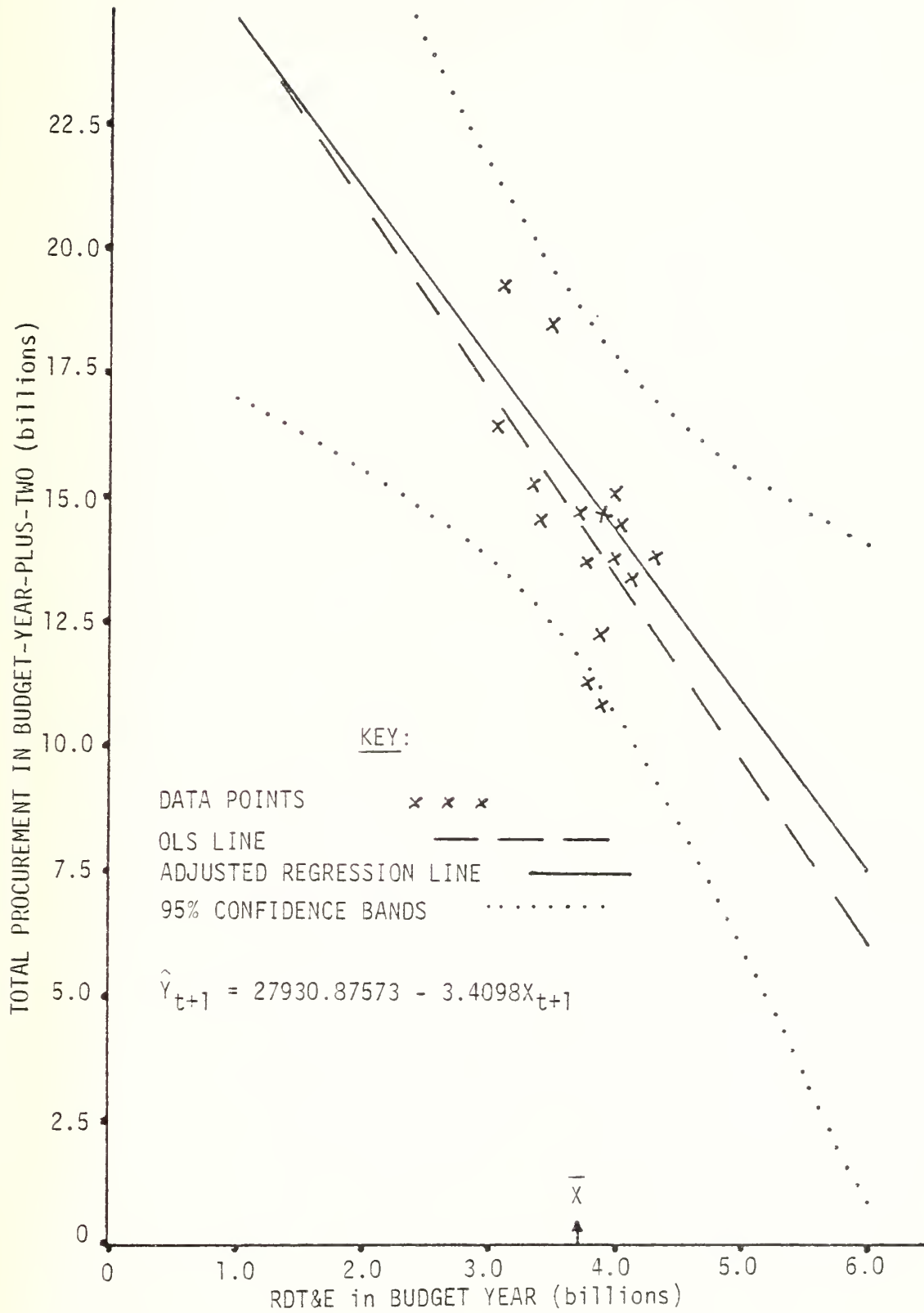
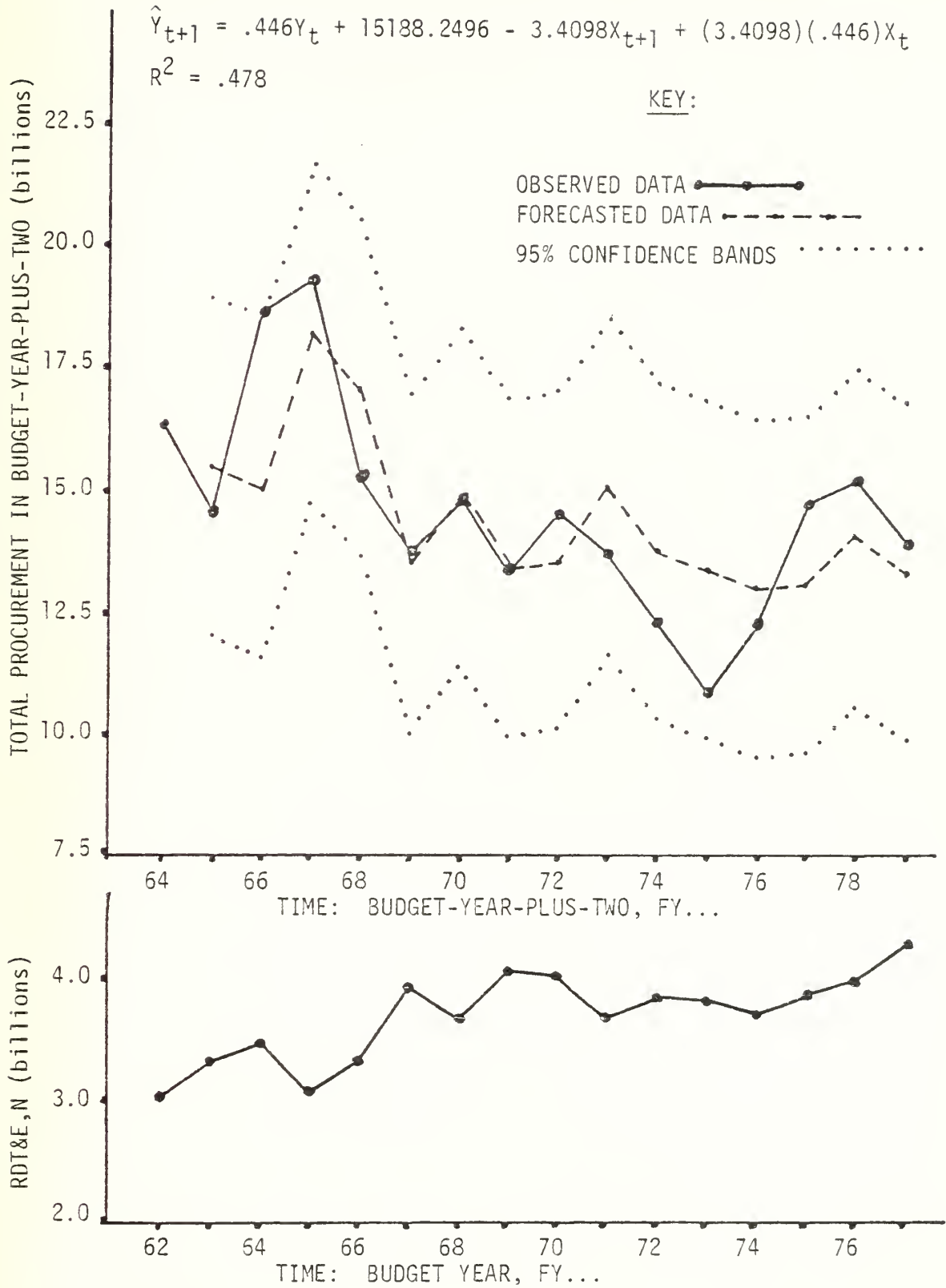




FIGURE 4







C. PROCUREMENT IN BUDGET-YEAR-PLUS-THREE VS. RDT&E,N  
IN BUDGET YEAR.

1. Observed Variables, Variables in Generalized  
Difference Form ( $r=.823$ ), and Ex Post Forecast.

FY	X	X*	FY	Y	Y*	$\hat{Y}_{t+1}$
62	3025	-----	65	14580	-----	-----
63	3394	904.425	66	18687	6687.66	15264
64	3374	679.738	67	19380	4000.599	16001
65	3087	228.721	68	15271	-678.74	16580
66	3332	791.399	69	13822	1253.967	15392
67	3961	1218.764	70	14801	3425.494	15866
68	3684	424.097	71	13405	1223.777	13573
69	4075	1043.068	72	14510	3477.685	14838
70	4011	657.275	73	13744	1802.27	14243
71	3718	416.947	74	12307	995.688	12676
72	3865	805.086	75	10870	750.339	13006
73	3841	660.105	76	12332	3378.583	11266
74	3755	593.857	77	14787	4637.764	12203
75	3893	802.635	78	15122	2952.299	15037
76	3991	787.061	79	13919	1473.594	15253

2. OLS Regression:  $Y = 23284.4885 - 2.3904 X$

3. Regression Line Adjusted for Serial Correlation:

$$\hat{Y}_{t+1} = rY_t + a(1-r) + bX_{t+1} - brX_t$$

$$\hat{Y}_{t+1} = (.823)(13919) - 261.2879 + 3.8988X_{t+1} - (3.8988)(.823)(3991)$$

$$\hat{Y}_{t+1} = -1611.922088 + 3.8988 X_{t+1}$$

4. Data Table:

$X_{t+1}$	$\hat{Y}_{t+1}$	$S_f^2$	$S_v$	$t_{.025;n-2}$	$S_v$
1000	2287	25236249.15	2854		6164
2000	6186	12816433.19	2034		4393
3000	10084	6110380.133	1404		3032
3674	12712	4813815.148	1246		2692
4000	13983	5118089.976	1285		2776
5000	17882	9839562.719	1782		3849
6000	21781	20274798.36	2558		5525



FIGURE 5

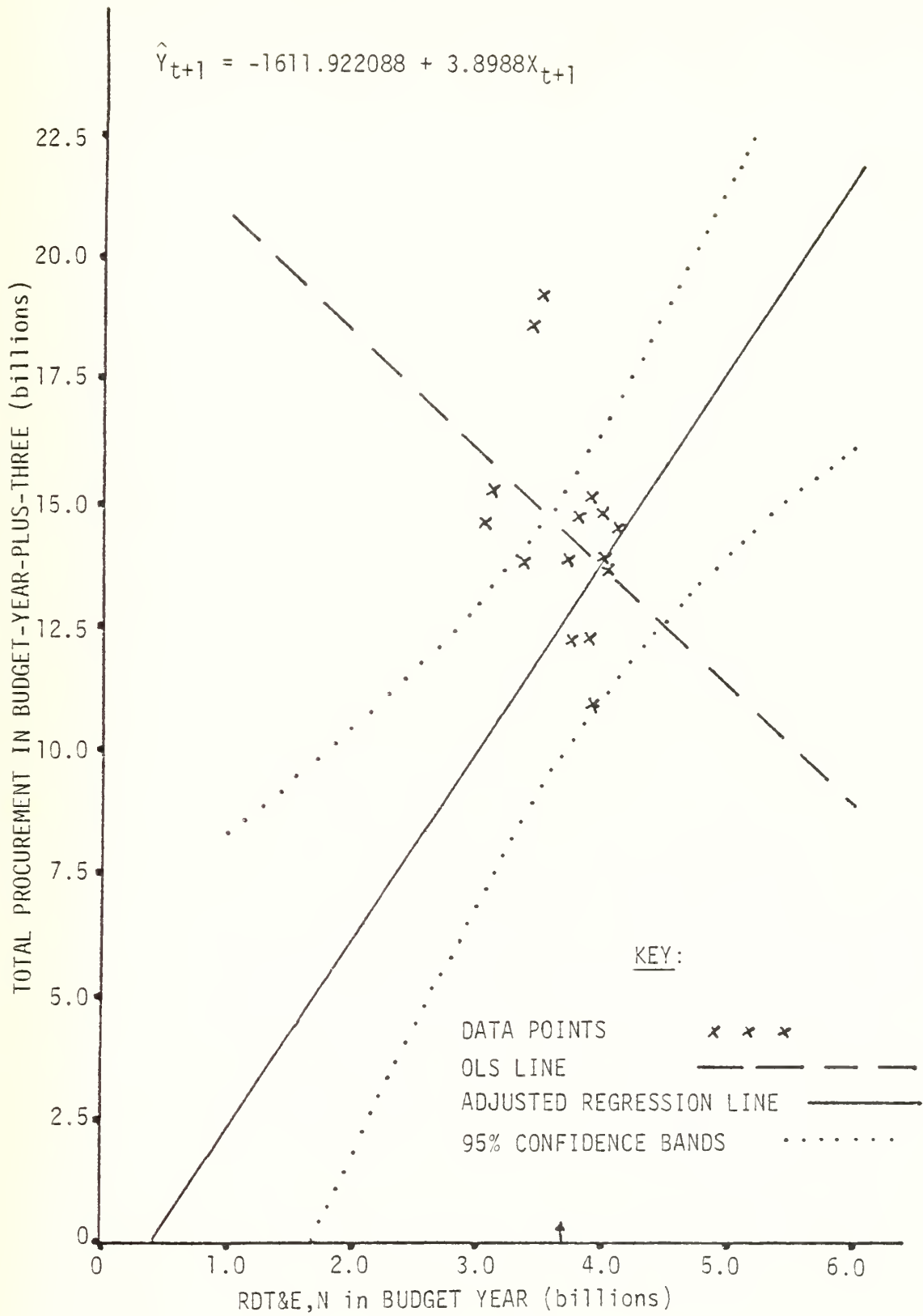




FIGURE 6

$$\hat{Y}_{t+1} = .823Y_t - 261.2879 + 3.8988X_{t+1} - (3.8988)(.823)X_t$$

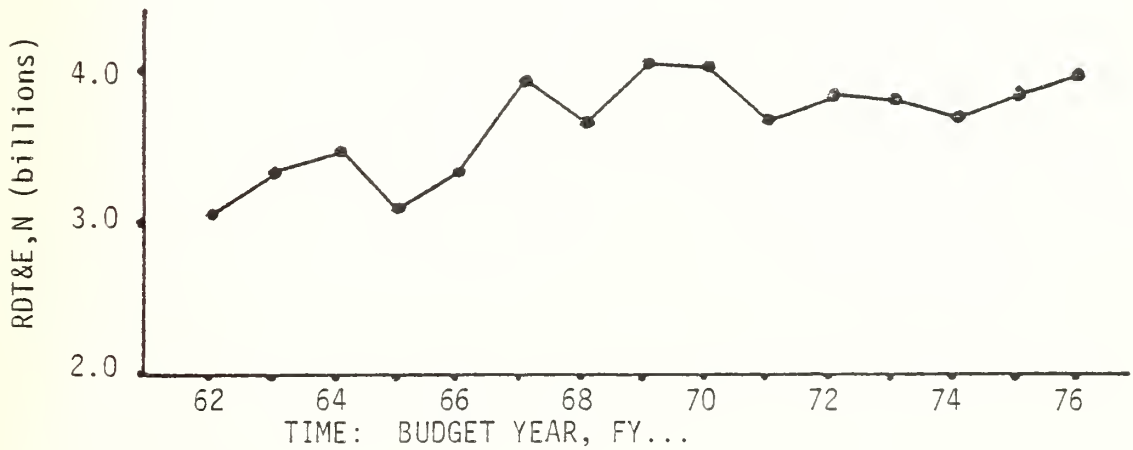
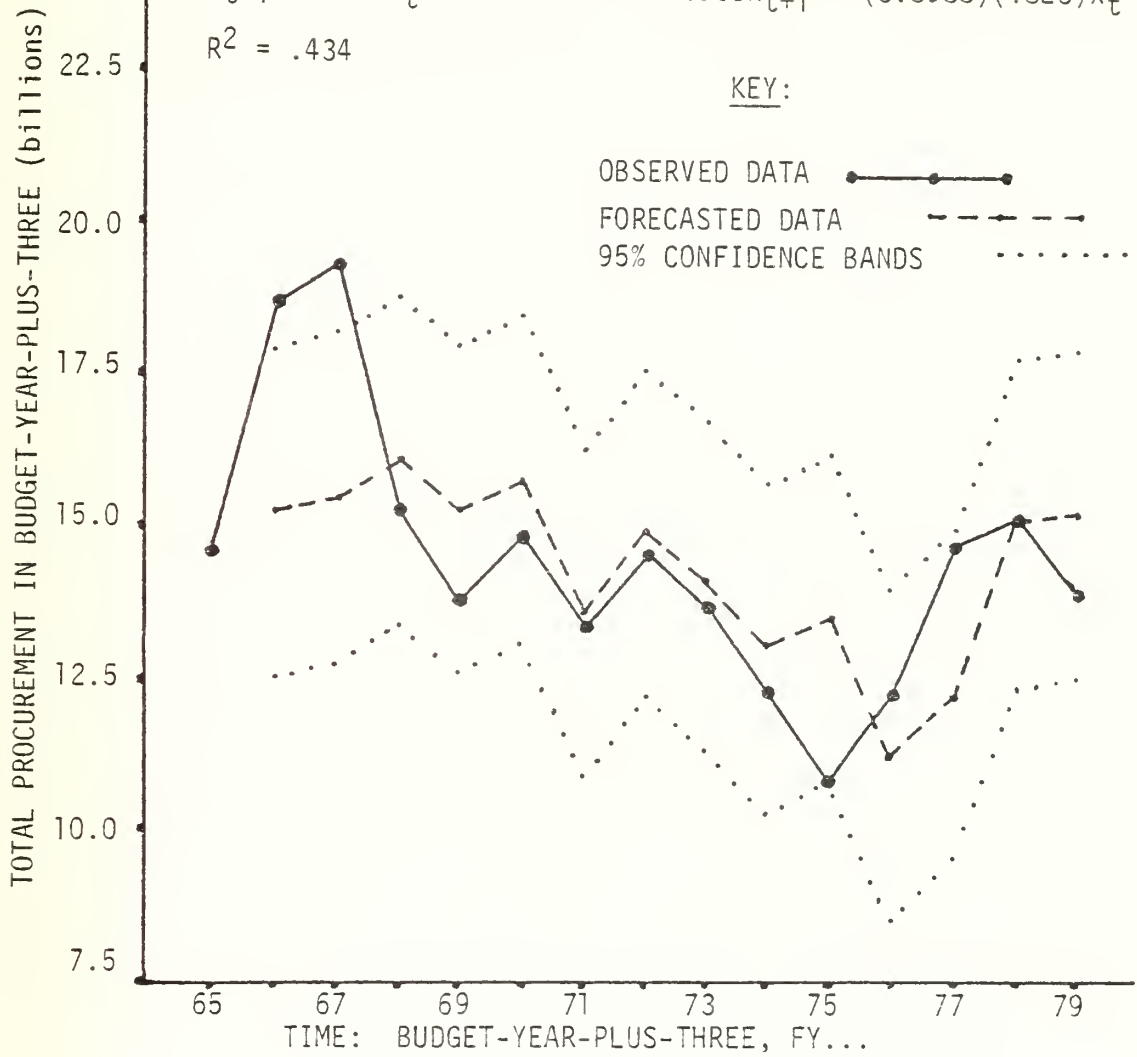
$$R^2 = .434$$

KEY:

OBSERVED DATA

FORECASTED DATA

95% CONFIDENCE BANDS





D. PROCUREMENT IN BUDGET-YEAR-PLUS-FOUR VS. RDT&E,N  
IN BUDGET YEAR:

1. Observed Variables, Variables in Generalized  
Difference Form (r=.600), and Ex Post Forecast:

FY	X	X*	FY	Y	Y*	$\hat{Y}_{t+1}$
62	3025	----	66	18687	----	----
63	3394	1579	67	19380	8167.8	16676
64	3473	1436.6	68	15271	3643.0	17058
65	3087	1003.2	69	13822	4659.4	14490
66	3332	1479.8	70	14801	6507.8	13734
67	3961	1961.8	71	13405	4524.4	14436
68	3684	1307.4	72	14510	6467	13443
69	4075	1864.6	73	13744	5038	14238
70	4011	1566	74	12307	4060.6	13708
71	3718	1311.4	75	10879	3494.8	12785
72	3865	1634.2	76	12332	5804.6	12005
73	3841	1522	77	14787	7387.8	12850
74	3755	1450.4	78	15122	6249.8	14305
75	3893	1640	79	13919	4845.8	14552

2. OLS Regression:  $Y = 29141.2369 - 4.0109X$

3. Regression Line Adjusted for Serial Correlation:

$$\hat{Y}_{t+1} = rY_t + a(1-r) + bX_{t+1} - brX_t$$

$$\hat{Y}_{t+1} = (.600)(13919) + 5089.0391 + .2376X_{t+1} - (.2376)(.600)(3893)$$

$$\hat{Y}_{t+1} = 12885.45302 + .2376 X_{t+1}$$

4. Data Table:

$X_{t+1}$	$\hat{Y}_{t+1}$	$S_f^2$	$S_v$	$t_{.025;n-2}$	$S_v$
1000	13123	21442577.92	3704		8072
2000	13361	10722192.65	2620		5708
3000	13598	4985714.989	1786		3892
3651	13753	3929622.474	1586		3456
4000	13836	4233144.939	1646		3687
5000	14073	8464482.5	2328		5072
6000	14311	17679727.67	3364		7330





FIGURE 7

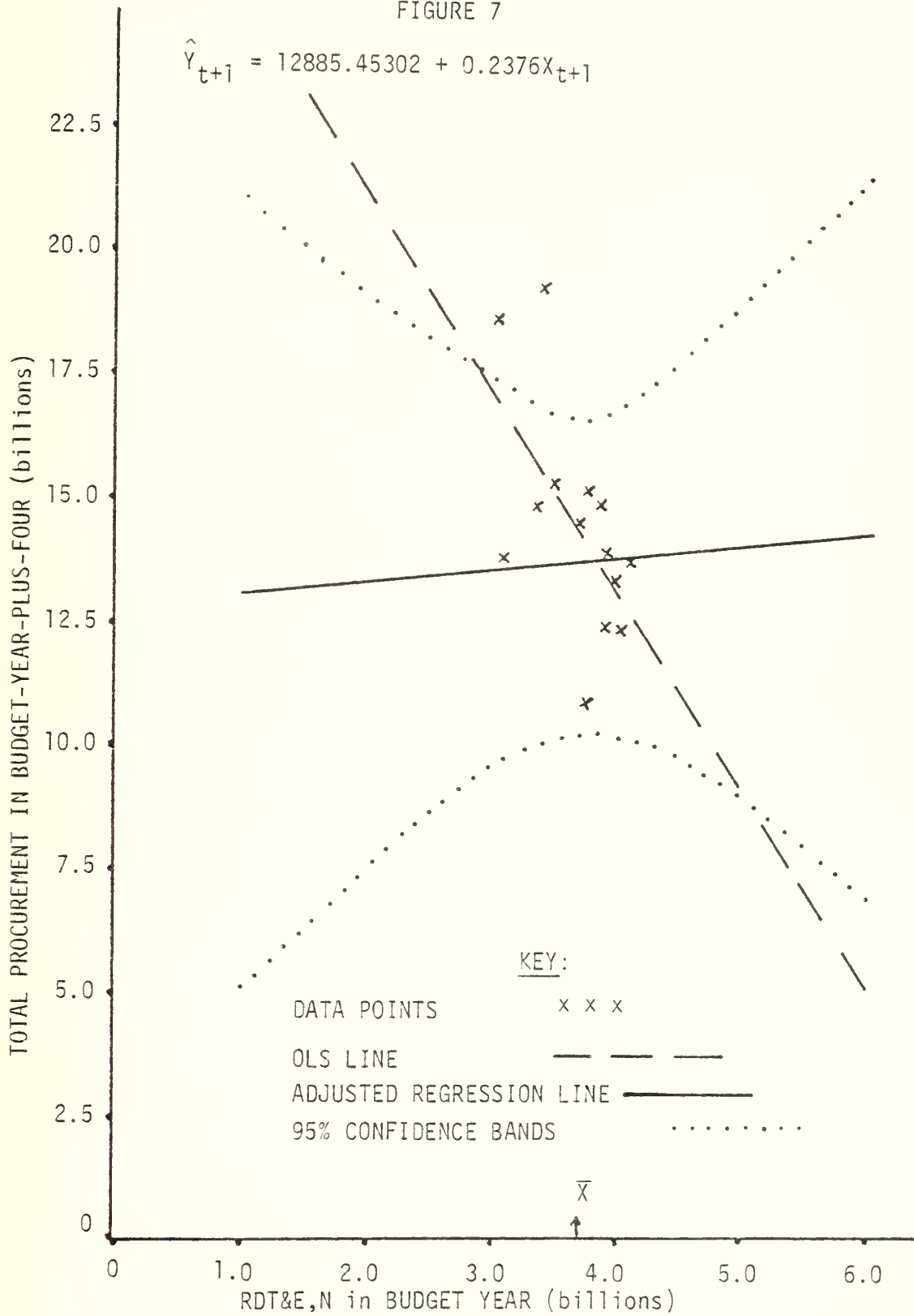
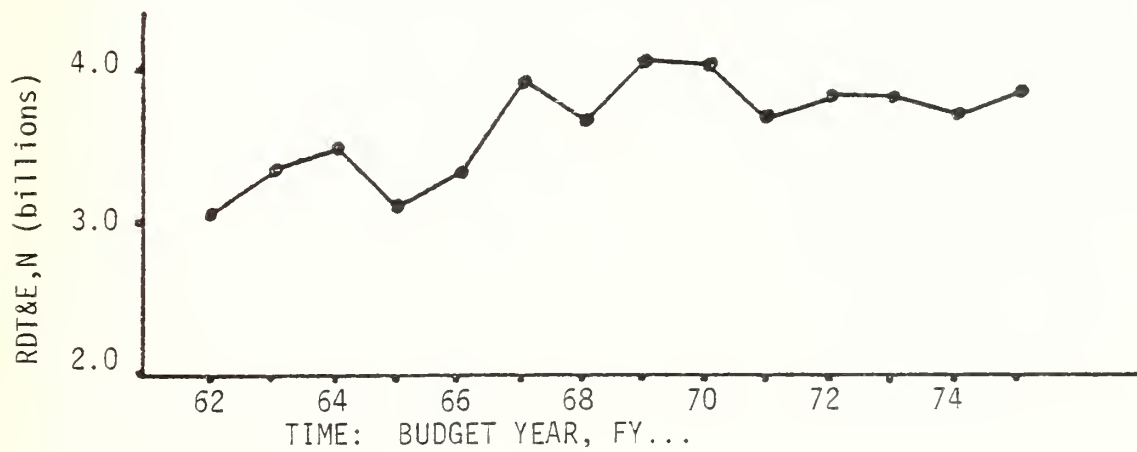
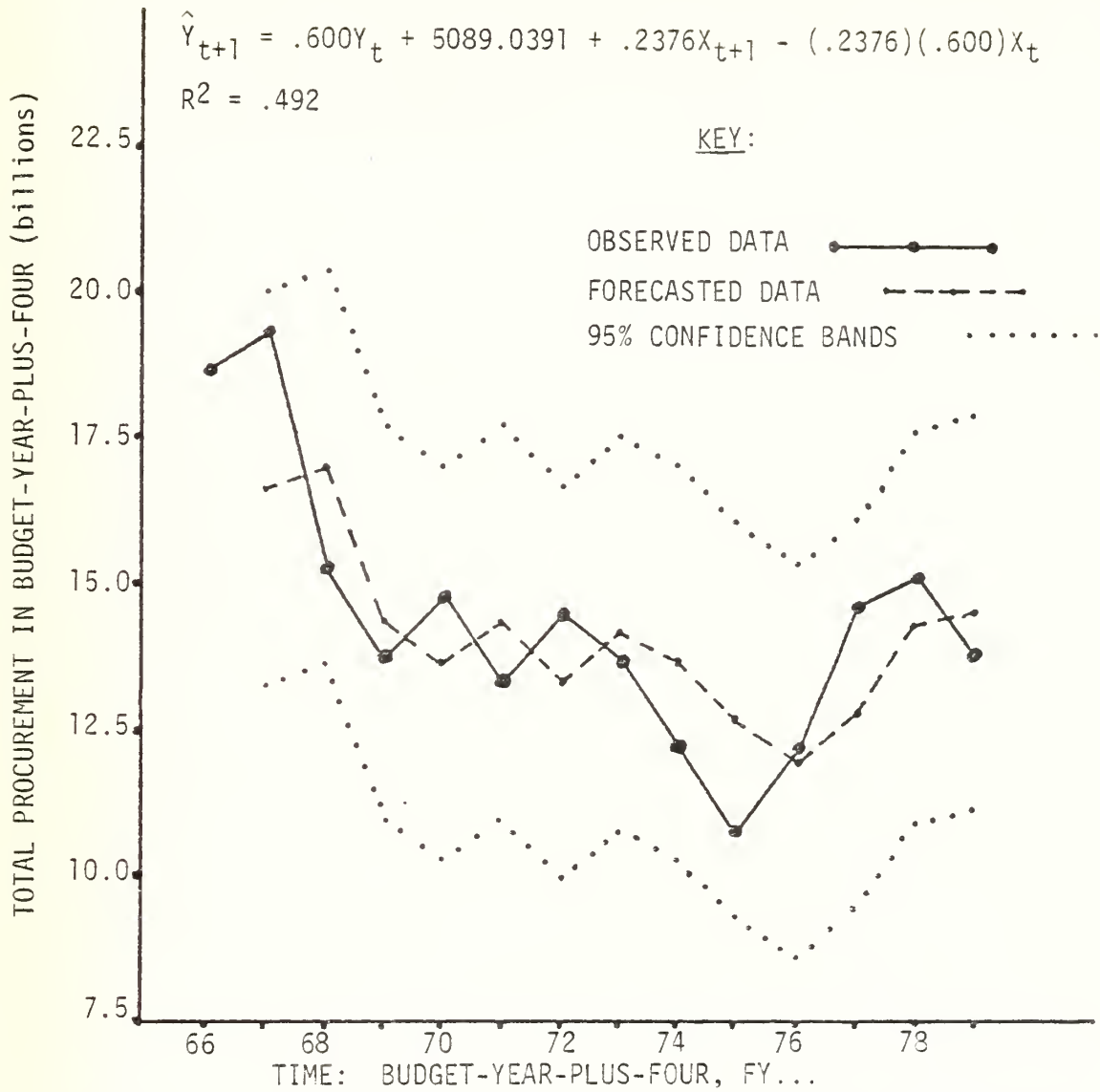




FIGURE 8





E. TOTAL PROCUREMENT IN PROGRAM YEARS VS. RDT&E,N  
IN BUDGET YEAR

1. Observed Variables, Variables in Generalized  
Difference Form ( $r=.863$ ), and Ex Post Forecast.

FY	X	X*	FY	Y	Y*	$\hat{Y}_{t+1}$
62	3025	----	63-66	69344	-----	----
63	3394	783.425	64-67	69100	9256.128	66403
64	3473	543.978	65-68	67921	8287.7	66729
65	3087	89.801	66-69	67164	8548.177	66732
66	3332	667.919	67-70	63277	5314.468	64780
67	3961	1085.484	68-71	57302	2693.949	60489
68	3684	265.657	69-72	56541	7089.374	57173
69	4075	895.708	70-73	56463	7668.117	55101
70	4011	494.275	71-74	53969	5341.431	55935
71	3718	256.507	72-75	51443	4867.753	54317
72	3865	656.366	73-76	49266	4870.691	51239
73	3841	505.505	74-77	50308	7791.442	49699
74	3755	440.217	75-78	53123	9707.196	50745
75	3893	652.435	76-79	56163	10317.851	52698

2. OLS Regression:  $Y = 122325.6933 - 17.4351 X$

3. Regression Line Adjusted for Serial Correlation

$$\hat{Y}_{t+1} = rY_t + a(1-r) + bX_{t+1} - brX_t$$

$$\hat{Y}_{t+1} = (.863)(56163) + 8317.3507 - 2.2449X_{t+1} + (2.2449)(.863)(3893)$$

$$\hat{Y}_{t+1} = 64328.11819 - 2.2449 X_{t+1}$$

4. Data Table

$X_{t+1}$	$\hat{Y}_{t+1}$	$S_f^2$	$S_v$	$t_{.025;n-2} S_v$
1000	62083	114633753.4	5409	11786
2000	59838	57321707.88	3825	8335
3000	57593	26654035	2608	5683
3651	56132	21008079.12	2316	5046
4000	55349	22630734.74	2403	5237
5000	53104	45251807.08	3398	7405
6000	50859	94517252.04	4912	10702



FIGURE 9

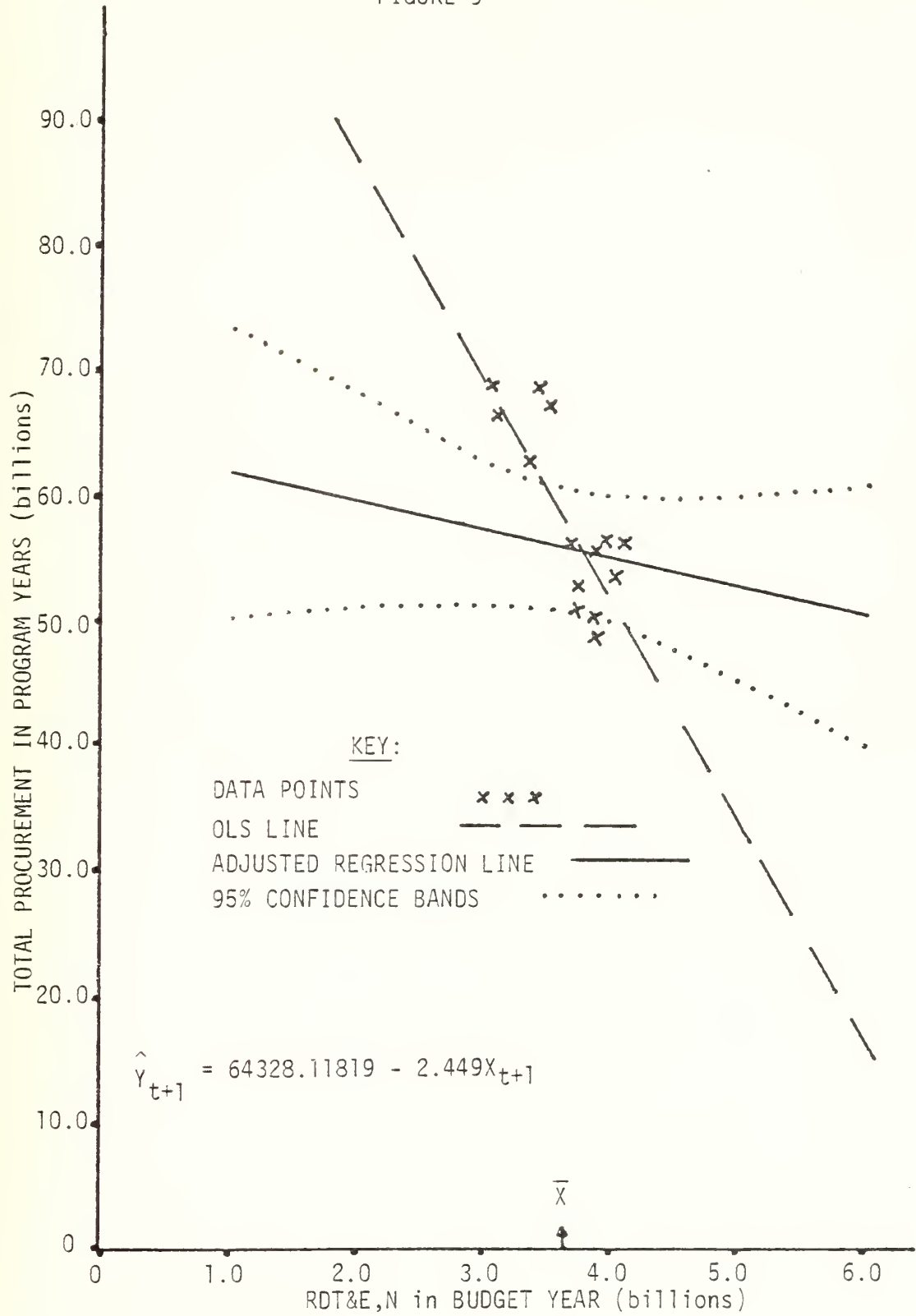
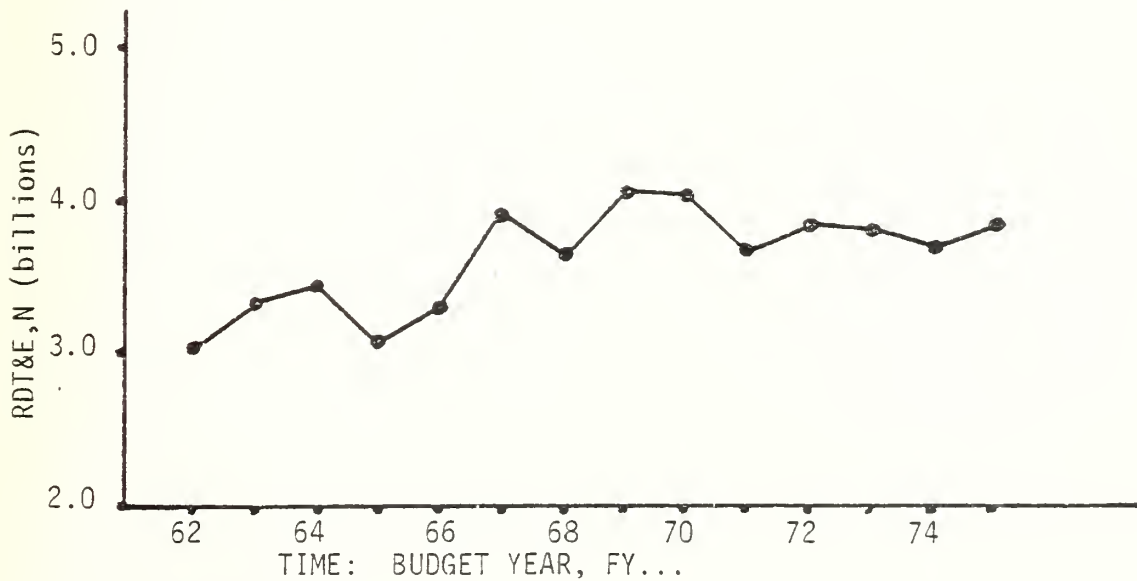
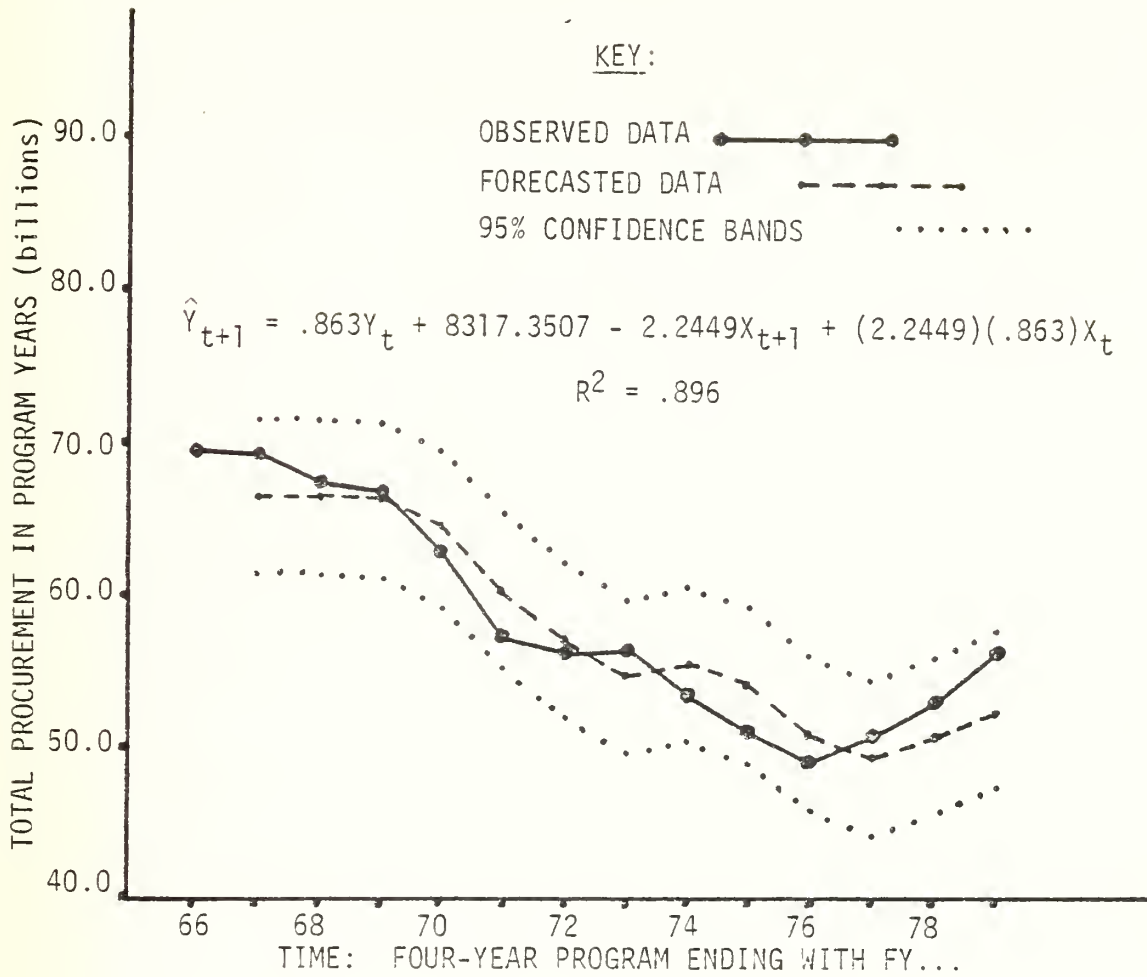






FIGURE 10





F. PAMN (WPN&APN) IN PROGRAM YEARS VS RDT&E,N  
IN BUDGET YEAR

1. Observed Variables, Variables in Generalized  
Difference Form ( $r=.821$ ), and Ex Post Forecast

FY	X	X*	FY	Y	Y*	$\hat{Y}_{t+1}$
62	3025	----	63-66	24781	-----	----
63	3394	910.475	64-67	25610	5264.799	24046
64	3373	686.526	65-68	26062	5036.19	25004
65	3087	235.667	66-69	26323	4926.098	25932
66	3332	797.573	67-70	24090	2478.817	25452
67	3961	1225.428	68-71	22157	2379.11	23089
68	3684	432.019	69-72	22188	3997.103	22484
69	4075	1050.436	70-73	21952	3735.652	21744
70	4011	665.425	71-74	22215	4192.408	22027
71	3718	424.969	72-75	21219	2980.485	22417
72	3865	812.522	73-76	19918	2497.201	21243
73	3841	667.835	74-77	20034	3681.322	20354
74	3755	601.539	75-78	21093	4645.086	20531
75	3893	810.145	76-79	22727	5409.647	21142

2. OLS Regression:  $Y = 40680.8239 - 4.8746 X$

3. Regression Line Adjusted for Serial Correlation

$$\hat{Y}_{t+1} = rY_t + a(1-r) + bX_{t+1} - brX_t$$

$$\begin{aligned}\hat{Y}_{t+1} &= (.821)(22727) - 4827.0128 - (1.2368)(X_{t+1}) \\ &\quad + (1.2368)(.821)(3893)\end{aligned}$$

$$\hat{Y}_{t+1} = 27438.88183 - 1.2368 X_{t+1}$$

4. Data Table

$X_{t+1}$	$\hat{Y}_{t+1}$	$S_f^2$	$S_v$	$t_{.025;n-2} S_v$
1000	26202	12029394.1	1980	4315
2000	24965	6015204.024	1400	3051
3000	23728	2797011.194	955	2081
2651	22923	2204537.98	848	1847
4000	22492	2374815.61	880	1917
5000	21255	4748617.272	1244	2711
6000	20018	9918416.18	1798	3918



FIGURE 11

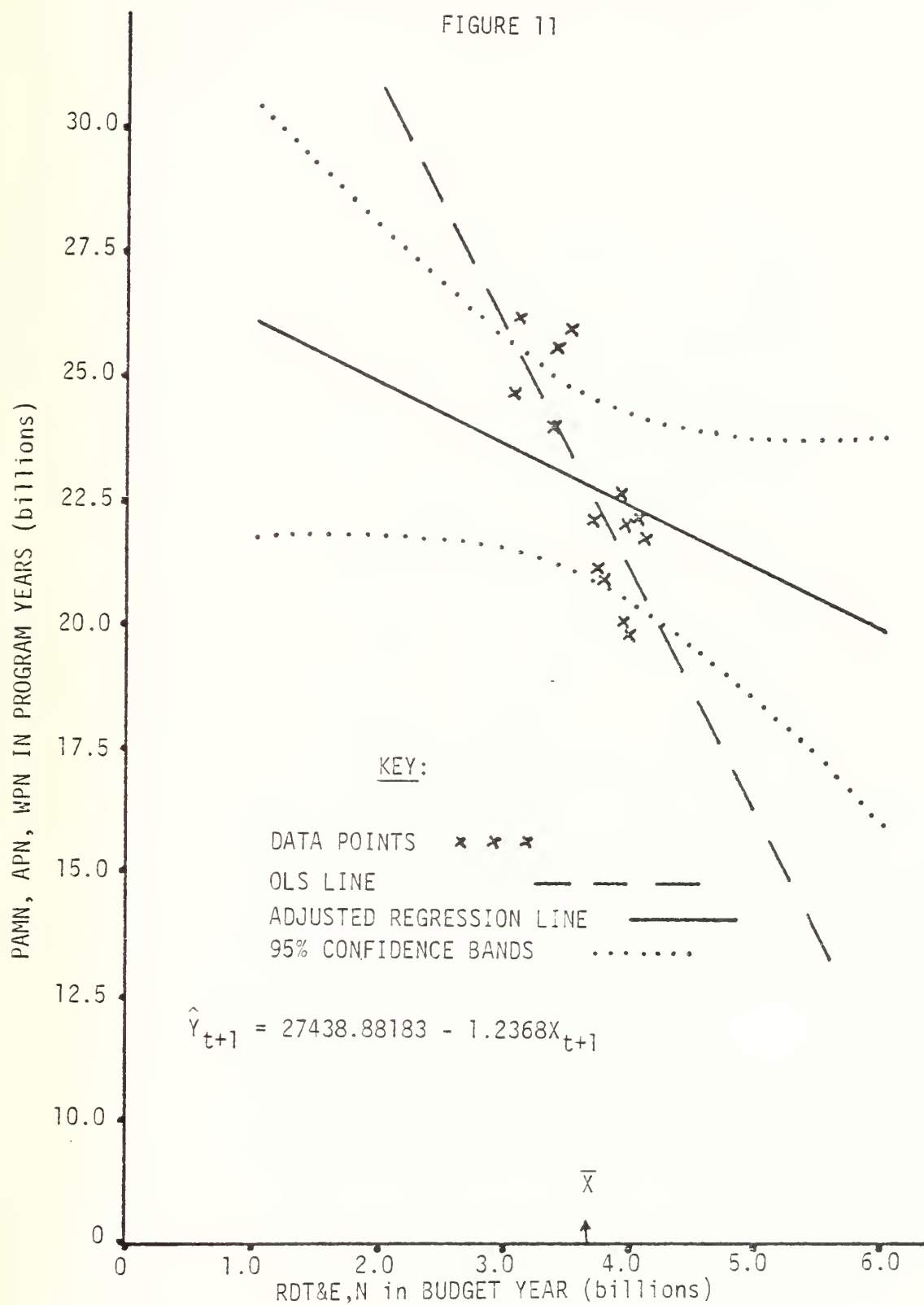
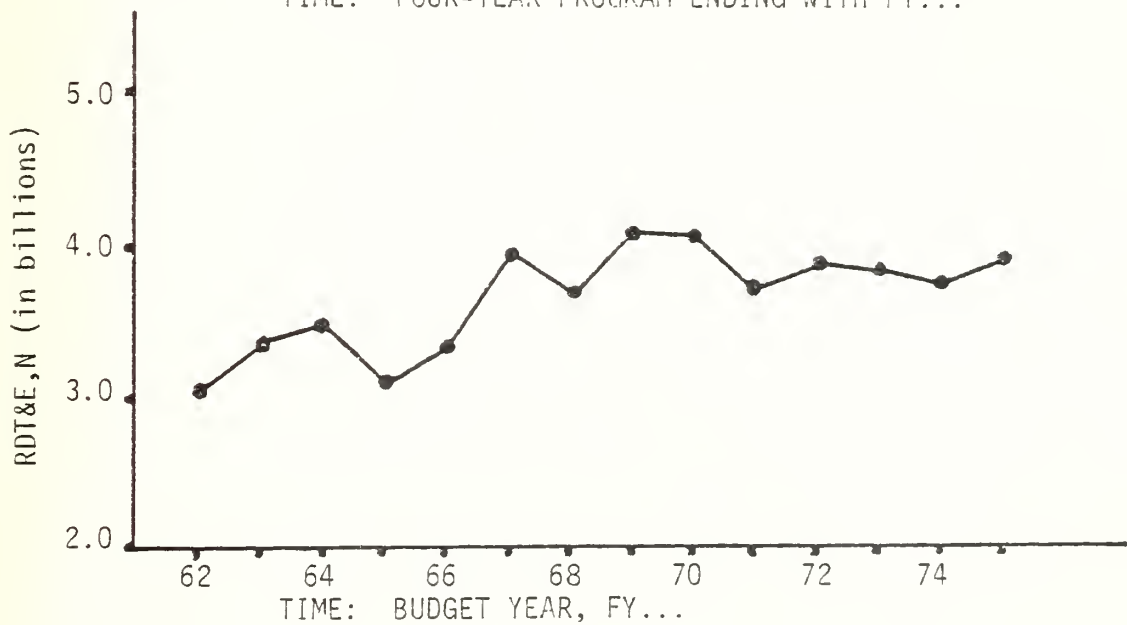
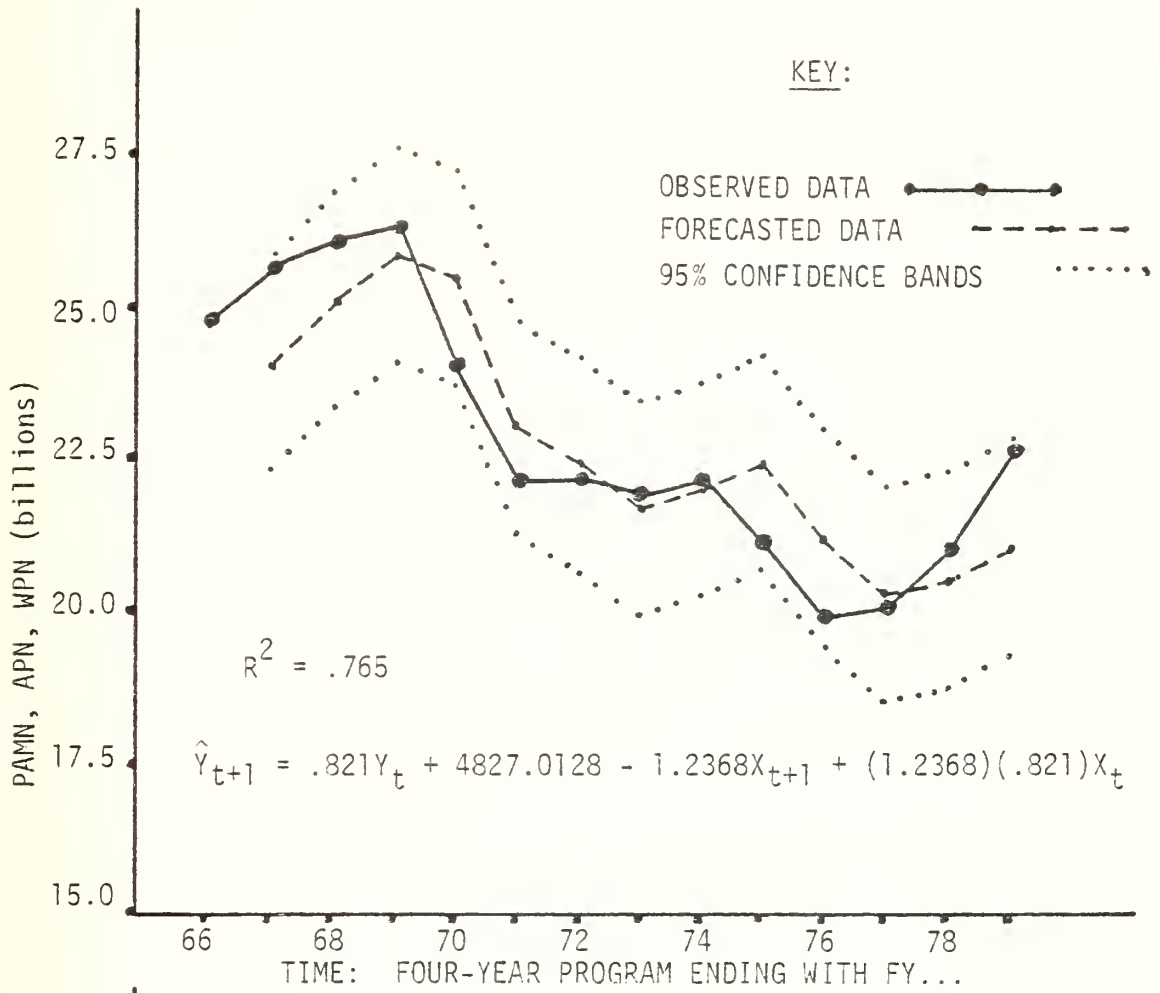




FIGURE 12







G. TOTAL PROCUREMENT IN THE PROGRAM YEARS VERSUS  
RDT&E,N IN THE BUDGET YEAR, USING ELEVEN MOST  
RECENT DATA POINTS ONLY

1. Observed Variables, Variables in Generalized  
Difference Form (r=.640), and Ex Post Forecast

FY	X	X*	FY	Y	Y*	$\hat{Y}_{t+1}$
65	3087	-----	66-69	67164	-----	-----
66	3332	1356.32	67-70	63277	20292.04	62071
67	3961	1838.52	68-71	57302	16804.72	59114
68	3684	1148.96	69-72	56541	19867.72	55966
69	4075	1717.24	70-73	56463	20276.76	54913
70	4011	1403	71-74	53969	17832.68	55176
71	3718	1150.96	72-75	51443	16902.84	53831
72	3865	1485.48	73-76	49266	16342.48	51881
73	3841	1367.4	74-77	50308	18777.76	50608
74	3755	1296.76	75-78	53123	20925.88	51343
75	3893	1489.8	76-79	56163	22164.28	52952

2. OLS Regression:  $Y = 105846.7778 - 13.3253 X$

3. Regression Line Adjusted for Serial Correlation:

$$\hat{Y}_{t+1} = rY_t + a(1-r) + bX_{t+1} - brX_t$$

$$\hat{Y}_{t+1} = (.640)(56163) + 20436.5695 - .9954X_{t+1} + (.9954)(.640)(3893)$$

$$\hat{Y}_{t+1} = 58860.94851 - .9954 X_{t+1}$$

4. Data Table:

$X_{t+1}$	$\hat{Y}_{t+1}$	$S_f^2$	$S_v$	$t_{.025;n-2} S_v$
1000	57866	144425746.7	9234	20888
2000	56870	68126434.4	6342	14346
3000	55875	25776334.75	3901	8824
3747	55131	16292824.35	3101	7016
4000	54879	17375447.77	3203	7245
5000	53884	42923773.44	5034	11387
6000	52889	102421311.8	7776	17590



FIGURE 13

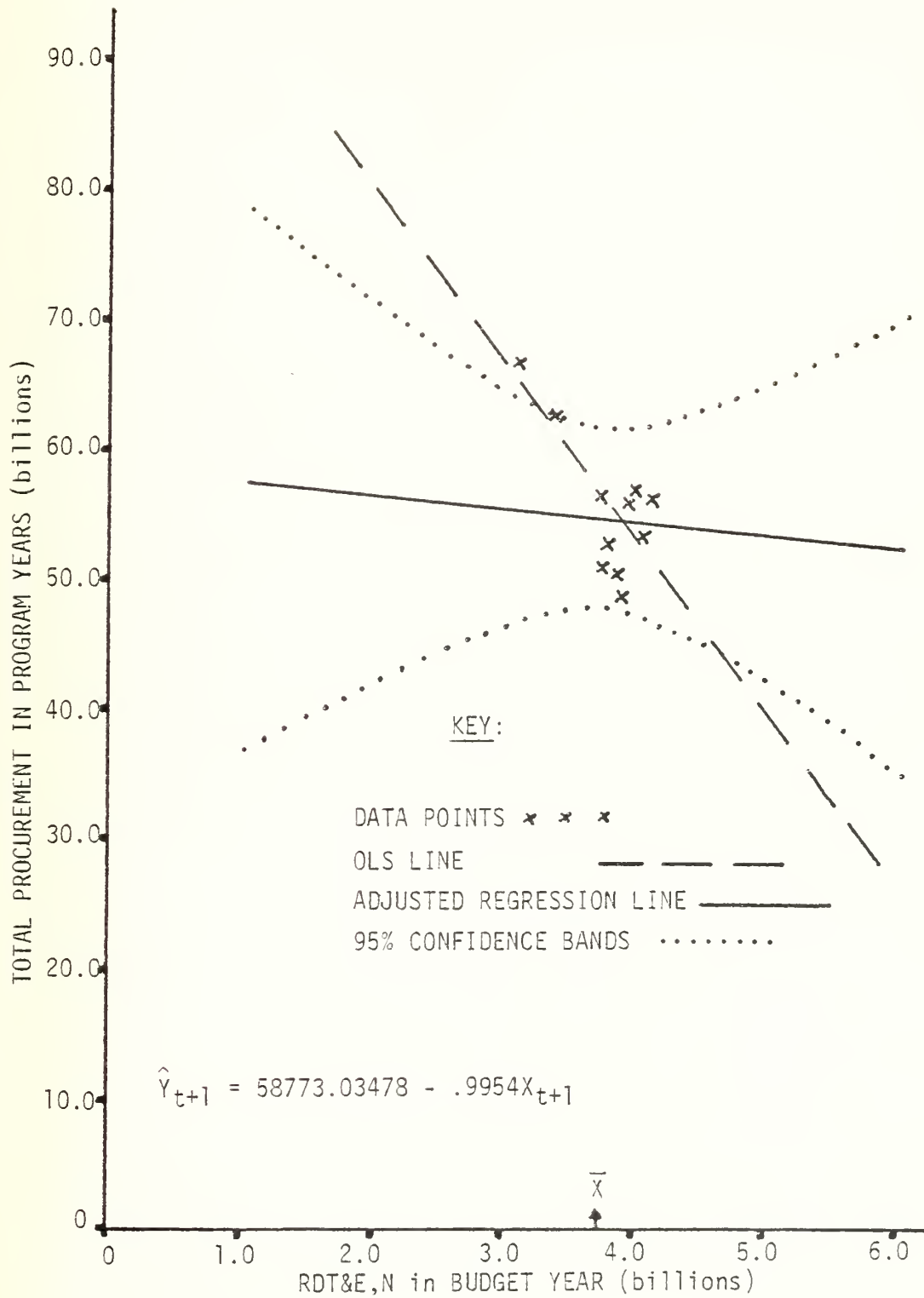
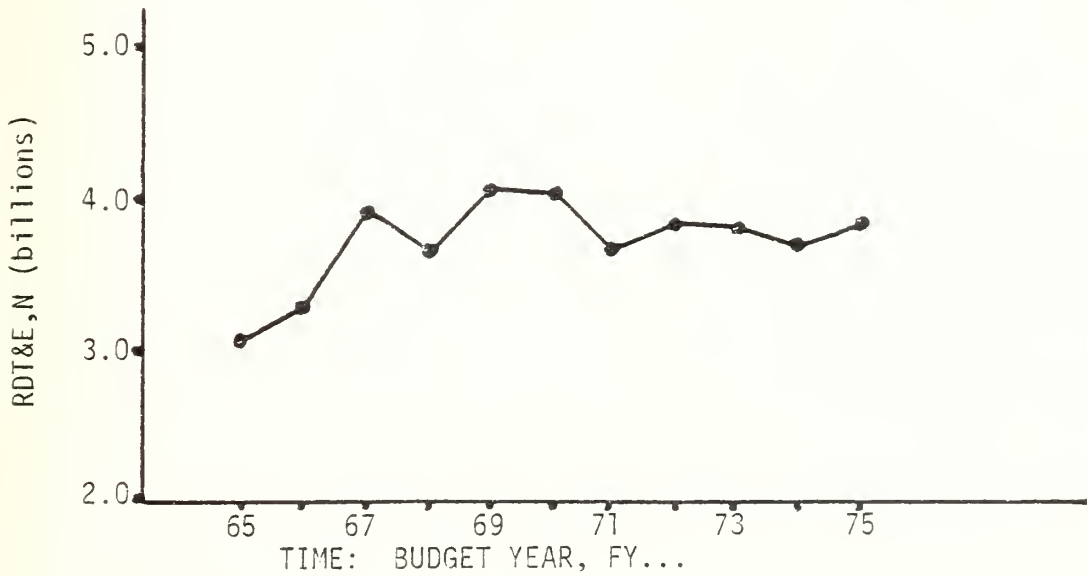
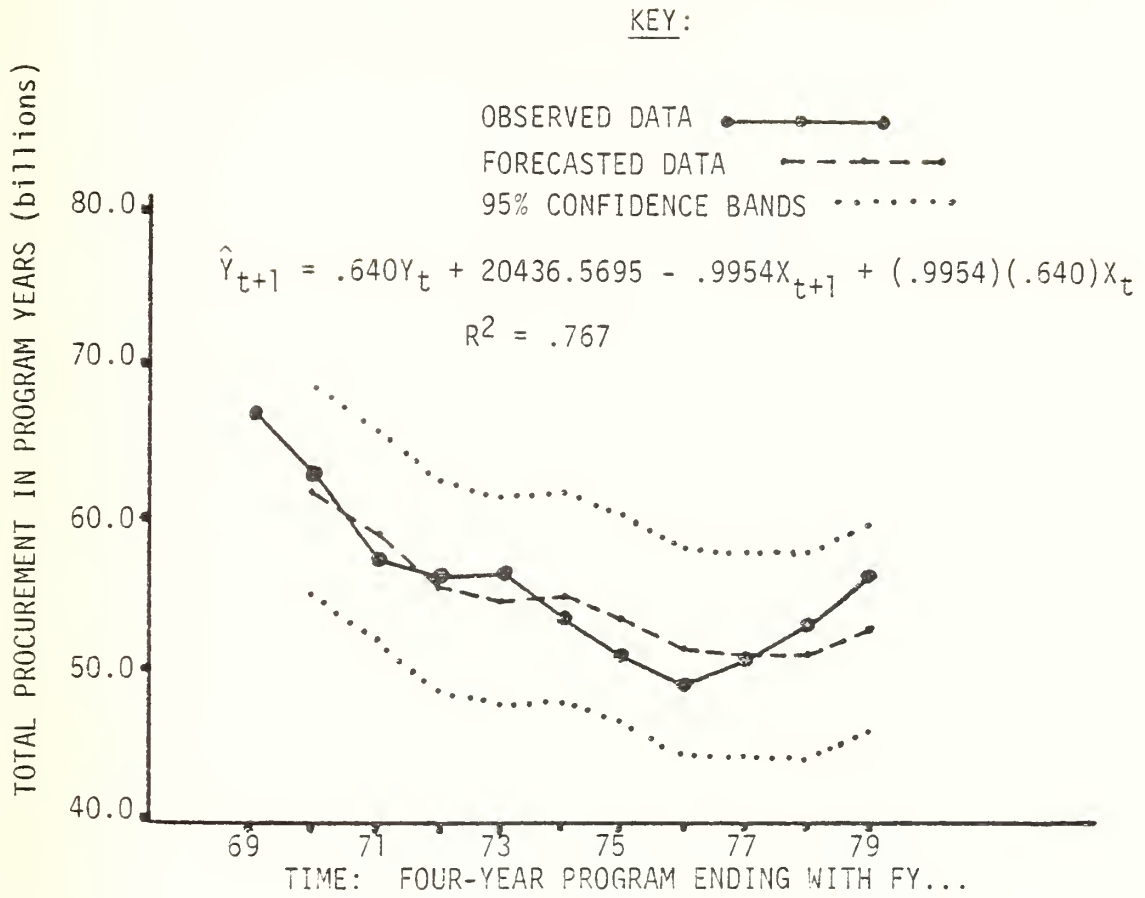




FIGURE 14





H. TOTAL PROCUREMENT IN PROGRAM YEARS VERSUS  
RDT&E,N IN BUDGET YEAR, USING EIGHT MOST  
RECENT DATA POINTS ONLY

1. Observed Variables, Variables in Generalized  
Difference Form (r=.501), and Ex Post Forecast

FY	X	X*	FY	Y	Y*	$\hat{Y}_{t+1}$
68	3684	-----	69-72	56541	-----	-----
69	4075	2229.316	70-73	56463	28135.959	56209
70	4011	1969.425	71-74	53969	25681.037	54787
71	3718	1708.489	72-75	51443	24404.531	52149
72	3865	2002.282	73-76	49266	23493.057	52447
73	3841	1904.635	74-77	50308	25625.734	50837
74	3755	1830.659	75-78	53123	27918.692	50569
75	3893	2011.745	76-79	56163	29548.377	53339

2. OLS Regression:  $Y = 35127.9406 + 4.742 X$

3. Regression Line Adjusted for Serial Correlation:

$$\hat{Y}_{t+1} = rY_t + a(1-r) + bX_{t+1} - brX_t$$

$$\hat{Y}_{t+1} = (.501)(56163) + 16018.8642 + (5.3216)X_{t+1} - (5.321)(.501)(3893)$$

$$\hat{Y}_{t+1} = 33777.31581 + 5.3216 X_{t+1}$$

4. Data Table:

$X_{t+1}$	$\hat{Y}_{t+1}$	$S_f^2$	$S_v$	$t_{.025;n-2} S_v$
1000	39099	572113395.9	20701	50654
2000	44421	247480431.1	13615	33315
3000	49742	60681226.99	6742	16497
3855	54292	10271802.58	2775	6787
4000	55064	11715783.51	2962	7249
5000	60385	100584100.7	8680	21239
6000	65707	327286178.6	15657	38312





FIGURE 15

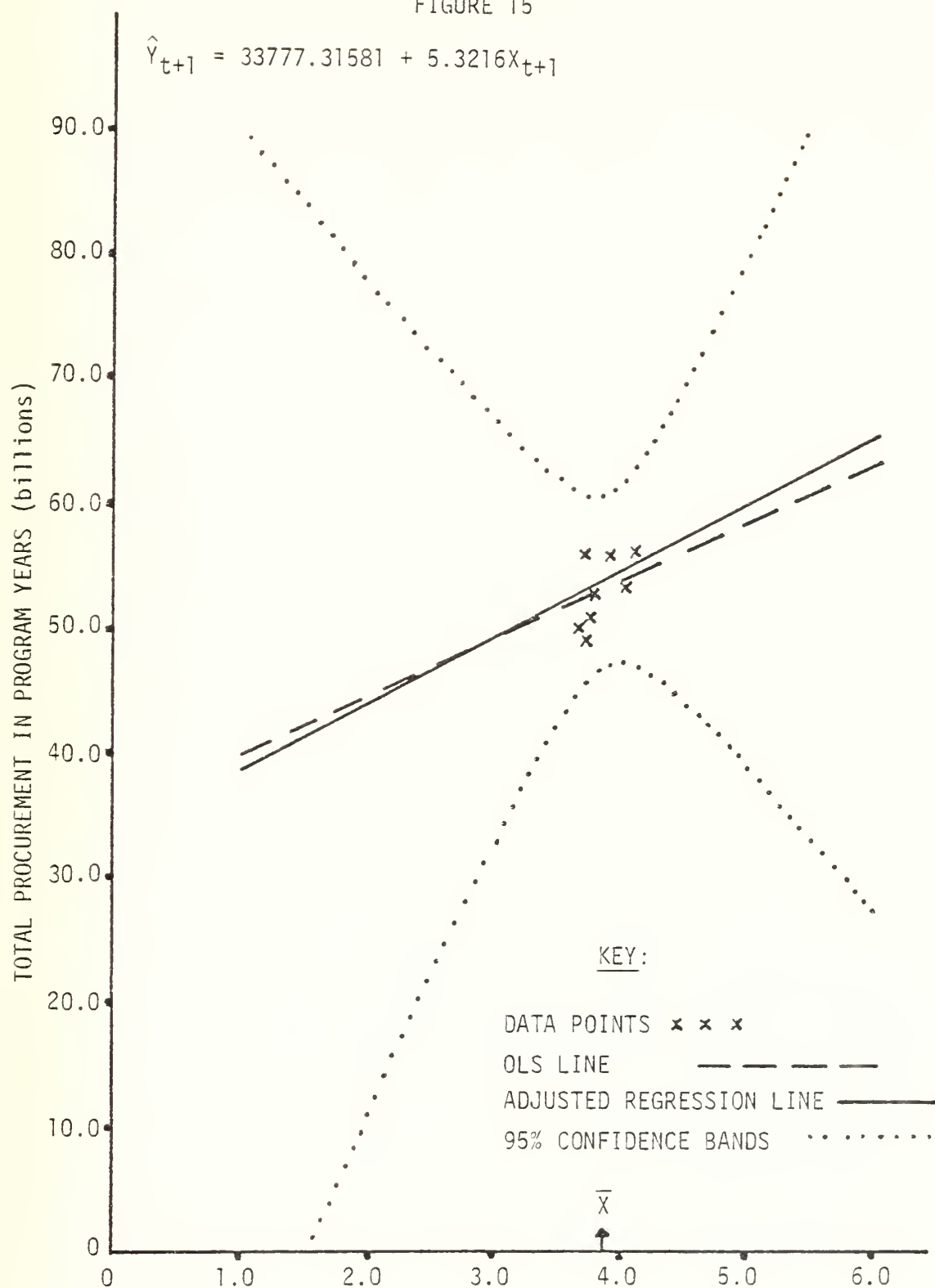
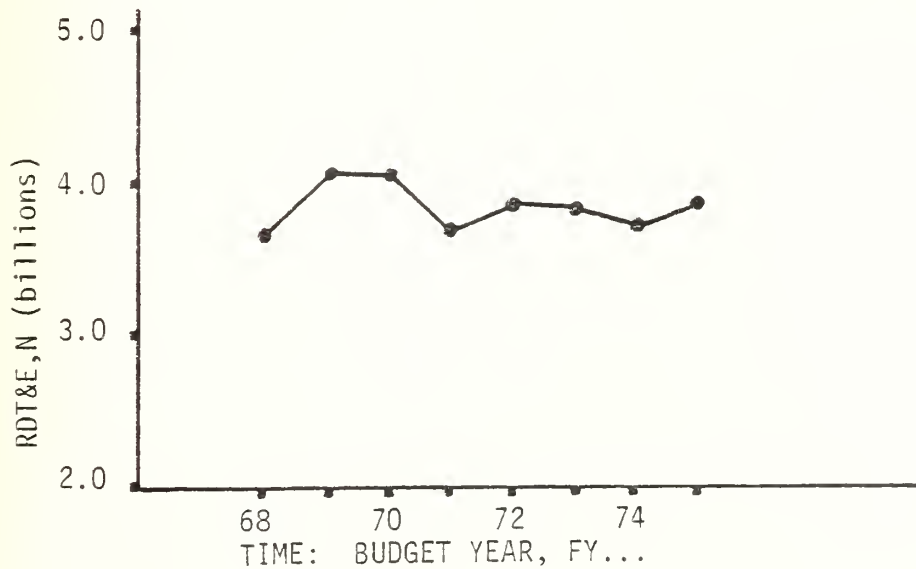
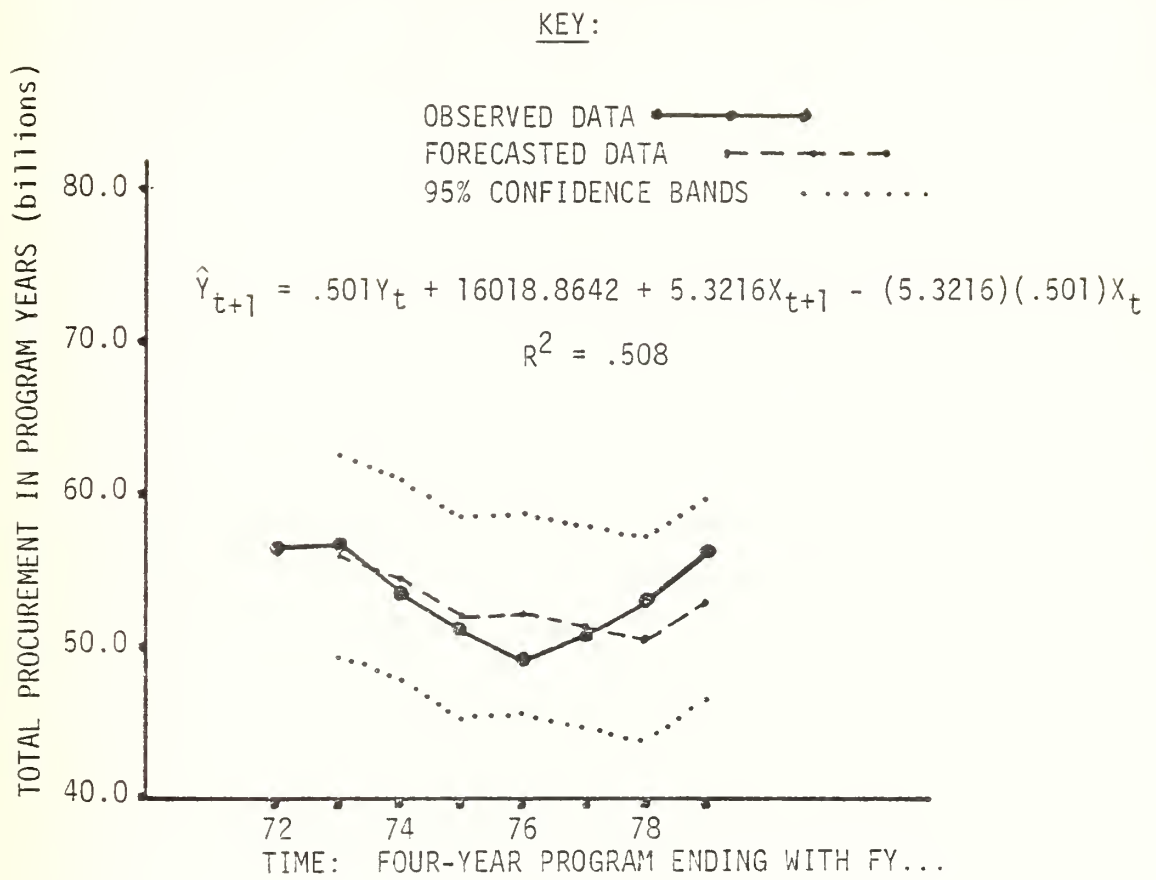




FIGURE 16





## V. THE CONCLUSIONS

### A. ANALYSIS OF REGRESSION RESULTS

Discussion of the regression results will proceed in generally the same sequence as the presentations in the previous section. Since the explanatory variable of each regression is RDT&E,N in the budget year, third-order headings which follow will refer only to the dependent variables of the regressions to be discussed.

#### 1. Forecasting A Single Year's Procurement

Sections IV.A, IV.B, IV.C, and IV.D present the results of the analyses of the relationships between current RDT&E,N and a single year of total Navy procurement one, two, three, and four years in the future, respectively. The results are not very impressive. Ex post forecasts results in  $R^2$  statistics of .383, .478, .434, and .492, indicating that in each case less than half of the procurement variance is "explained" by the earlier effort in RDT&E. In addition, the widths of the 95% confidence intervals about these models' point estimates are excessive. The average value of the dependent variable during the period under study is approximately \$15000 million, and these models provide confidence intervals of between \$5384 million and \$7286 million in width (both sides). Such statistical accuracy would appear to be of little use, even at the 95% level of significance. Finally, these four regressions



appear to have very little relation to one another. The adjusted regression lines have a sharply negative slope for the first two analyses. The third year's adjusted regression line is sharply positive in slope, and the fourth year's regression provides a line of only slightly positive slope. One would expect either more consistency among these regressions or some sort of trend. Neither characteristic is in evidence, and the absence of any pattern suggests that the time period covered by the dependent variable (one year) may be too short.

## 2. Forecasting Total Procurement in the Program Years

Section IV.E displays the results of the analysis of the relationship between RDT&E,N in the budget year and total procurement in the following four years (the program years) collectively rather than individually. The ex post forecast in this case results in a  $R^2$  of .896 and a 95% confidence interval of \$10092 million. The  $R^2$  statistic is impressive in that nearly ninety percent of the variation of the dependent variable is "explained" by the model, and the confidence interval, when compared to the average value of the dependent variable during the period studied, \$58670 million, suggests that the statistical reliability of this model is superior to those produced by the single year analyses.

In spite of the apparent success of this analysis, one serious difficulty remains to be discussed: the negative slope of the adjusted regression. The OPNAV/NAVCOMPT





analysis at the very least implied that the relationship between RDT&E and future procurement was direct in nature; that the more spent now on RDT&E, the more we could expect to spend on future procurement. However, both the regression results and visual inspection of the data plotted over time (Figure 10) reveal that, on the macro level since 1962, the overall trend in total Navy procurement has been negative, while the trend in RDT&E,N has been positive. This conflict leads logically to expansion of the study in two directions, both of which will be discussed in the sections to follow.

3. Forecasting Aircraft and Missile (PAMN, APN, WPN) Procurement in the Program Years

In order to explore the possibility of a closer and/or more direct relationship existing between RDT&E and selected future procurements, the analysis presented in Section IV.F was conducted. Of the five current Department-of-the-Navy procurement accounts, PAMN (divided into WPN and APN since 1974) was thought to be probably the most influenced by research and development. Thus, an analysis of budget year RDT&E,N in relation to program years' collective PAMN might prove revealing.

The analysis resulted in ex post forecasts and a  $R^2$  statistic of .765 and a confidence interval of \$3695 million in comparison with average value of the dependent variable of \$22884 million. This  $R^2$  value is a little less than that of the previous analysis, but the confidence



interval is a little narrower. The indication is that this relationship is neither significantly better nor significantly worse than that matching RDT&E with total procurement. In addition, the model produced has a negative slope as did the previous regression. Thus, the expected results did not materialize. Although further attempts at factoring the data may well yield more useful results, this study explores another avenue.

#### 4. Total Procurement in the Program Years (Reducing the Time Span)

In attempting to forecast by means of time-series data, there always exists a danger that one or more of the basic relationships among the variables involved may have changed during the period under study. Concern for this danger seems particularly appropriate with regard to this analysis (specifically, the analysis presented in Section IV.E above). The time period studied includes the Vietnam War and the extraordinary impact it must have had on specific Navy procurement actions and on the entire Navy budget in general. In addition, the very nature of changing technology provides a logical basis for arguments that earlier data (e.g. data prior to 1970 or 1973) are not valid; and visual inspection of the data tends to support this contention. Note that the last few data-point relationships seem to indicate a direct relationship between the variables: as RDT&E begins to increase, procurement increases also. See Figure 12.



In response to this, regressions were conducted using fewer data points; that is, earlier data were ignored. Sections IV.G and IV.H present analyses which use only the previous eleven and eight data pairs, respectively. The relationship is again between RDT&E,N in the budget year and total Navy procurement in the program years. The results are interesting in that the slope of the adjusted regression lines become more positive as more early data are ignored; this indicates that the supposition that the basic relationship has changed may have some validity. At the same time, however, the width and shape of the 95% confidence interval appear to have deteriorated to the point of making forecasts much less reliable. If the regression resulting from an analysis of only the last eight data points (IV.H) is the most representative of the true relationship between the variables, then there is no alternative but to accept a 95% confidence interval which is \$13574 million wide at best (i.e. the next explanatory variable is equal to the average of the previous eight) and which will increase rapidly as the next explanatory variable varies from the average.

Note also that the  $R^2$  statistics for the ex post forecasts conducted using only the most recent eleven and eight data points fall to .767 and .508, respectively. Although this indicates a deterioration in the goodness of fit, the amount of variation in the observed dependent



variable is also a good deal less in these regressions than in those conducted with all fourteen data points. Since the  $R^2$  statistic is constructed using the squares of the deviations about the mean of the observed values of the dependent variable, it becomes more difficult, proportionately, to achieve the same  $R^2$  statistic when these deviations are smaller. In other words, the relatively low  $R^2$  statistics may not in these cases be cause for rejection of these regressions.

An additional interesting result occurs when comparing the predictions of the three different models for the same reasonable value of the explanatory variable, for instance \$4000 million (by reasonable, we mean in the range of experience of the explanatory variable). The point estimates ( $\hat{Y}_{t+1}$ ) produced by the fourteen-, eleven-, and eight-data-point regressions are \$55349 million, \$54879 million, and \$55064 million, respectively. Thus, the point-estimate forecasts of the models are so close as to make their differences negligible. This is partially explained by the fact that the three models all have the most recent eight data points in common and that, by design, the more recent data have more impact on the model. Unfortunately, neither the proximity of the estimates nor the explanation for it helps to resolve the question of the true nature of the relationship between these two variables. The point estimates may be close, but each model responds quite





differently to changes in the explanatory variable. Thus, the choice of model is still crucial to the budget analyst, who is most often faced with decisions of an incremental nature.

## B. CLOSING STATEMENTS

### 1. Suggestions for Further Study

Although necessarily limited, this study may well provide a stepping-off point for further analyses. It would seem logical that the predictability of future procurement could be improved if additional explanatory variables were included in the model (e.g. GNP, total DOD budget, total Federal Budget, the unemployment rate). Lack of sufficient and relevant time-series data might in this way be overcome by pooling whatever time-series data are available with cross-section data. Of course, the methodology of multi-variable forecasting and the process of handling error disturbances are considerably more sophisticated than those used in this thesis. However, in view of the results achieved with just RDT&E, more useful and accurate predictions might be expected.

### 2. Hypothesis

With regard to the general working hypothesis proposed at the outset, it is concluded that there does exist a statistically valid predictive relationship between current Navy research and development and future Navy procurement, taking the program years as a whole. Whether



the relationships discovered in this thesis are close enough to prove useful to those who shape future Navy budgets remains open to question. Probably the most common failing of forecasting with time-series data is due to an unwarranted emphasis on the past rather than the future. Additionally, the temptation to attribute cause-and-effect qualities to purely predictive relationships is always present. The quality and usefulness of the models developed above or those which may follow should be based upon how well they predict the future, and, if a basic relationship can change, it must always be kept in mind that during the period being predicted, it just might!



APPENDIX A

THE OPNAV MEMORANDUM

3 111



DEPARTMENT OF THE NAVY  
OFFICE OF THE CHIEF OF NAVAL OPERATIONS  
WASHINGTON, D.C. 20350

IN REPLY REFER TO

Ser 922E21/587526

24 APR 1978

MEMORANDUM FOR SUPERINTENDENT, NAVAL POSTGRADUATE SCHOOL

Subj: Proposed Study Subject for Financial Management  
Students

Encl: (1) Discussion Paper

The purpose of this memorandum is to recommend a subject for study by your financial management students. I believe the study would provide results useful to those of us involved in shaping future Navy budgets and be an excellent project for a master's thesis.

The ever increasing complexity and cost of modern weapons systems is a familiar theme and we are indeed seeing more and more instances where the development of a promising new system is terminated simply because its predicted procurement costs make the system non-affordable. Nonetheless, the research and development program for the Department of Defense continues to receive increased emphasis during each year's budget deliberations. For example, the Navy's Research, Development, Test and Evaluation (RDT&E) appropriation for FY 1979 is funded at a level which provides a program real growth of approximately six percent over the FY 1978 level. In order to project the magnitude of future Navy budgets that can be anticipated as a result of the continued emphasis in research and development, my staff recently prepared an analysis of the potential procurement costs inherent in the on-going R&D programs presently funded in the RDT&E appropriation. The objective of the analysis was to develop, if possible, a prediction model that would help answer the question .... "Given a certain level of funding in research and development programs, what follow-on procurement costs can be expected?"

Although the analysis performed by my staff was intentionally limited, it did produce a rough indicator of approximately four dollars of procurement costs for every dollar of R&D, and yielded several interesting observations. For example, one program had an estimated procurement cost 33 times greater than its development cost, while other programs were noted to cost more to develop than to procure. Enclosure (1) provides additional background and a discussion of the approach used by my staff.



Subj: Proposed Study Subject for Financial Management  
Students (continued)

It is anticipated that appropriate research and analysis of the historical relationship between known procurement and development costs would produce numerical factors that reflect the number of procurement dollars required for every dollar of R&D. It is envisioned that the development programs would be categorized by some appropriate scheme such as functional type or mission area, e.g. -- aircraft, missiles, radar systems, sonar systems, etc., and that there would be a different factor for each category. The factors could be used as models to provide at least a rough answer to questions such as.... "If I have \$10 million RDT&E funds invested in advanced surface-sonar systems development programs, how many follow-on procurement dollars will be required?" In order to keep the study effort to a manageable level and within the ability of the students to accomplish as a thesis project, I recommend that the scope be limited to purely financial analysis without regard to the cost-effectiveness of the various weapon systems.

My point of contact for this proposed area of study is Mr. Charles P. Nemfakos, Associate Director, Budget. I will welcome any comments that you or your staff may have concerning this project.





## RETURN ON INVESTMENT IN R&D PROGRAMS

o The best indicator of the amount of future procurement dollars associated with new weapons systems now in development is an analysis of those programs in the engineering development stage of the total research and development program. It is these programs that have passed a major milestone in the system acquisition decision process and are the most likely to complete development and enter production. Many of the programs in engineering development already have budget quality estimates of their procurement price tag. For those programs whose procurement cost has not yet been priced out, we can at least obtain an order-of-magnitude, ball-park estimate of procurement cost using an empirically derived prediction factor. In order to derive such a factor for FY 1979, NAVCOMPT analyzed a representative sample of programs in engineering development in FY 1979 for which budget quality estimates of total development and total procurement costs were available. From the analysis a relationship of approximately four dollars of procurement for every dollar of R&D was derived. Using this predictor, we filled in the holes in the procurement cost estimates associated with our R&D programs in engineering development.

o The NAVCOMPT analysis used a very small data base of approximately 20 programs, as shown in Tab 1. These programs were all in the FY 1979 budget and in the engineering development stage of their development program. Each of these programs had progressed to the point that budget-quality estimates of the total R&D costs and total procurement costs were available. The programs were selected in such a manner as to provide a cross-section sample of the various development technologies within the total R&D programs.

o A more accurate analysis of the relationship between procurement and development costs would, of course, require a larger data base. The minimum requirement is that both total R&D and procurement costs be known -- thus the data base is largely historical in nature. Prior-year RDT&E budgets will necessarily provide the majority of programs in the sample as these budgets will contain more programs for which actual total R&D and procurement costs are available. Current year and budget year budgets also can be analyzed as budget-quality estimates of total R&D and procurement costs can be considered as "known" costs.

o In order to obtain return-on-investment factors that accurately describe the sample, each programs' contribution must be weighted by the ratio of its dollar value to the total dollar value of the sample. For example, there may be programs whose procurement-to-development cost factor is 40, but whose

ENCLOSURE (1)



impact on the overall factor is minimal because that program's R&D dollar value represented only one percent of the total sample's dollar value.

o The NAVCOMPT analysis considered only total procurement and total R&D costs. The possible affect of unit cost and production quantities was not analyzed. A more extensive study of procurement and R&D cost relationships should consider the impact of a large production quantity or a production run over a long period of time.



SAMPLE PROGRAMS

<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>
<u>Program</u>	<u>P/R</u>	<u>FY 79 AMT</u> <u>(\$ in M's)</u>	<u>Fraction</u> <u>of Sample</u>	<u>Weighted</u> <u>Factor</u>
F-18	5.6	473.6	.42	2.35
Lamps III	4.7	124.5	.11	.52
TACTAS	8.1	25.2	.02	.16
HARM	4.8	43.4	.04	.19
TOMAHAWK	1.8	152.1	.13	.23
STD MSL IMP	3.5	49.1	.04	.14
TRIDENT I MSL	2.2	191.8	.17	.37
SURTASS	5.3	6.6	.006	.01
ASPJ	.6	10.2	.009	.01
MCLWG	3.7	1.9	.002	.01
ABN ASW Pods	5.7	1.0	.001	.01
Adaptive BOM	4.4	5.8	.005	.02
SPN-42 RADAR	4.5	3.2	.003	.01
Spec W/F Craft	.6	6.0	.005	.01
ADV RADAR WARNING	33.2	.6	.0005	.02
Helo Night Vision	11.8	5.5	.005	.06
Air-Air MSL SYS	.4	28.5	.03	.01
CIC CONV	8.0	<u>7.1</u>	<u>.006</u>	<u>.05</u>
		1136.4	1.000	4.20

FY 79 Weighted Multiplier (Procurement to R&D)= 4.2



SAMPLE PROGRAMS -- LEGEND

<u>COLUMN</u>	<u>DESCRIPTION</u>
1	Program short title
2	Ratio of total procurement costs to total R&D costs
3	Amount of dollars budgeted in the FY 79 RDT&EN budget
4	Fraction representing each programs' share of the total sample
5	Weighted procurement-to-development factor obtained by multiplying columns 2 and 4





FY 1979 RESEARCH & DEVELOPMENT

**R&D COST OF  
PROGRAMS IN ENGINEERING DEVELOPMENT**  
(IN BILLIONS OF DOLLARS)

FY 79 BUDGET	COST TO COMPLETE DEVELOPMENT	TOTAL R&D FY 79-83
\$1.6	\$3.9	\$5.5



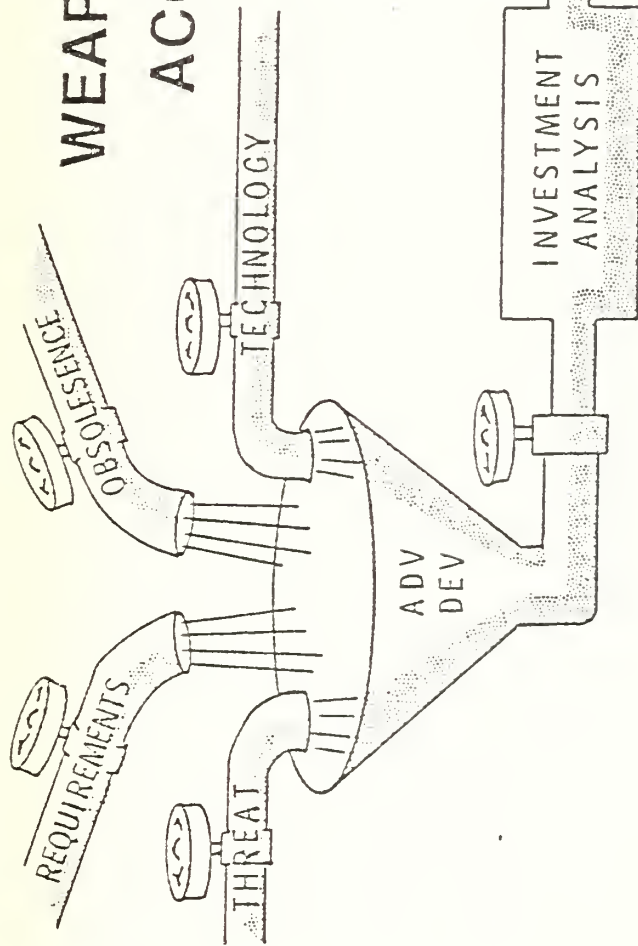
FY 1979 RESEARCH & DEVELOPMENT

**ESTIMATED PROCUREMENT COST OF  
R&D PROGRAMS IN ENGINEERING DEVELOPMENT**  
(IN BILLIONS OF DOLLARS)

COST OF PROGRAMS PRICED OUT	PROJECTED COST OF REMAINING PROGRAMS	TOTAL ESTIMATED PROCUREMENT COST
\$27.5	\$8.5	\$36



# WEAPON SYSTEMS ACQUISITION

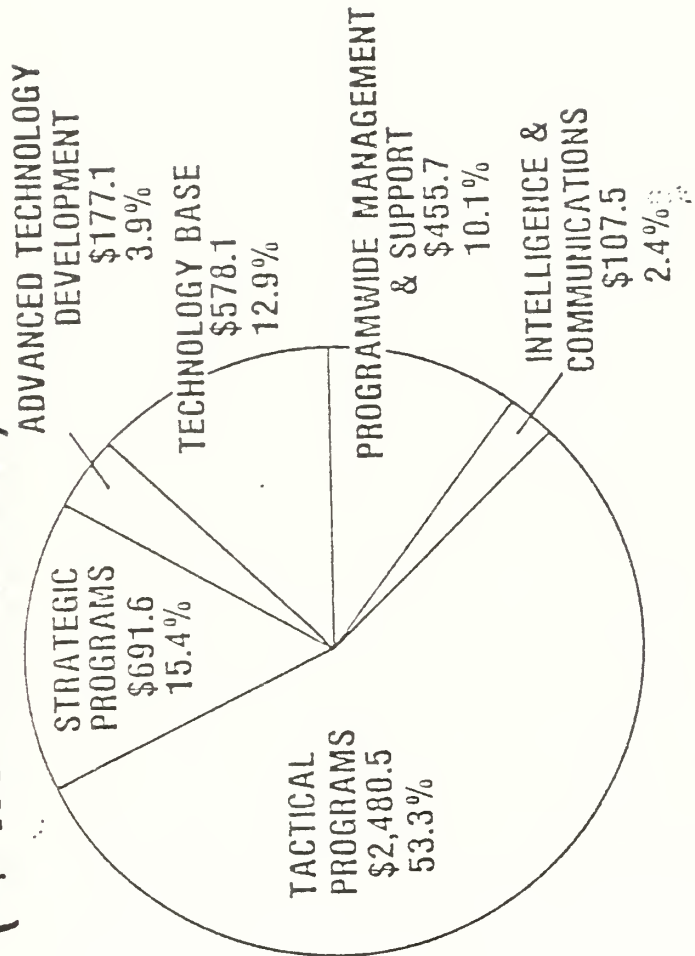


Where Do You Turn The Valve ?



# RESEARCH, DEVELOPMENT, TEST & EVALUATION, NAVY FY 1979

( \$ IN MILLIONS )



FY 1978 \$4,021.8	FY 1979 \$4,490.5	Δ \$ + 468.7
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# RESEARCH, DEVELOPMENT, TEST AND EVALUATION, NAVY (\$ MILLIONS)

	FY 1977	FY 1978	FY 1979
<u>PROGRAM HIGHLIGHTS:</u>	<b>\$3,800.1</b>	<b>\$4,027.8</b>	<b>\$4,490.5</b>
F-18 A/C	340.6	625.1	473.6
TRIDENT MISSILE	568.1	332.7	206.8
TRIDENT SUBMARINE	75.3	68.6	58.8
FBM SYSTEMS	113.0	129.8	135.9
TOMAHAWK MISSILE	106.8	210.3	143.1
LAMPS III	72.1	106.4	124.3
AV8B A/C	33.6	59.8	85.6
CSEDS	82.8	35.5	37.2
STANDARD MISSILES	17.8	19.5	58.6
SSBM SECURITY	29.8	37.9	37.2
VSTOL A/C DEVELOPMENT	12.4	22.5	52.5
HARM	30.0	29.7	43.4
ADVANCED ASW TORPEDO	25.4	25.0	44.3
ELF COMMUNICATORS	14.8	15.0	40.5



## APPENDIX B

### GLOSSARY OF TERMS AND ABBREVIATIONS

- Adjusted regression - An ordinary least squares regression which has been corrected for the serial correlation of the error terms [Refs. 10 and 12].
- APN - Appropriation title; Aircraft Procurement, Navy [Ref. 8].
- Appropriation - An annual authorization by Act of Congress to incur obligations for specified purposes and to make payments out of the Treasury. Synonyms: budget authority and new obligational authority [Ref. 5].
- Authorization - Substantive law which must be passed by Congress prior to any appropriation which specifies the amount and purposes for which money may be used. This requirement, which originally applied only to procurement of aircraft, missiles, and ships, has been expanded year-by-year to other categories until now it includes procurement of tracked combat vehicles and other weapons, RDT&E, military construction, torpedoes, reserve and active duty personnel strength [Ref. 4].
- Autoregression - A condition in which the error terms from different observations are correlated; the effect of an error disturbance in one period carries over into another period. Synonym: serial correlation [Refs. 10 and 12].
- Budget activity - The major subdivisions of each budget appropriation account as submitted to and approved by Congress (e.g., the budget activities as of fiscal year 1974 for the RDT&E,N appropriation are: Technology base, advanced technology development, strategic programs, tactical programs, intelligence and communications, program-wide management and support) [Ref. 2].



- Budget authority - An annual authorization by act of Congress to incur obligations for specific purposes and to make payments out of the Treasury. Synonyms: appropriation, new obligational authority [Ref. 7].
- Budget plan - That portion of the programming-and-financing section of the Federal budget request which shows by budget activity the amounts for procurement actions programmed and the manner in which the total amount is being financed [Refs. 7 and 8].
- Budget year - The current fiscal year plus one [Ref. 5].
- Budgeting - The process of translating approved resource requirements (manpower and material) into time-phased financial requirements [Ref. 5].
- Constant dollars - Costs expressed in terms of the price levels prevailing in the base year (FY 1979 in this case) [Ref. 5].
- Crosswalking - The process of transforming or translating the budget from DOD program category to appropriation budget activity and vice versa [Ref. 1].
- Current dollars - Costs expressed in terms of the price levels prevailing when those costs were incurred, obligated, and/or expended [Ref. 5].
- DOD program category - One of the ten major program categories outlined by the Department of Defense which are objective-, goal-, mission-, and/or output-oriented [Ref. 4].
- Econometrics - The development and use of mathematical models representing portions of the real world [Ref. 12].
- Economic forecasting - The quantitative estimation about the likelihood of future events based on past and current information [Ref. 12].
- Ex post forecast - A quantitative estimation about the likelihood of an event during a past time period when the value of both explanatory and dependent variables are known with certainty [Ref. 12].



- Expenditure - A charge against available funds which represent the actual payment of cash. Synonym: outlay [Ref. 5].
- New obligational authority (NOA) - An annual authorization by Act of Congress to incur obligations for specified purposes and to make payments out of the Treasury. Synonym: appropriation, budget authority [Ref. 5].
- Obligation - A legal reservation of a specified amount of an appropriation for expenditure [Ref. 5].
- OPN - An appropriation title: Other Procurement, Navy [Ref. 8].
- Ordinary least squares (OLS) regression - A procedure for determining the statistical relationship between two variables by calculating the equation for a straight line which minimizes the sum of the squared deviations (observed-calculated) of the dependent variable [Ref. 11].
- Outlay - A charge against available funds representing the actual payment of cash. Synonym: expenditure [Ref. 7].
- PAMN - An old appropriation title: Procurement of Aircraft and Missiles, Navy. (This appropriation was divided into APN and WPN in 1974) [Ref. 8].
- PMC - An appropriation title: Procurement, Marine Corps [Ref. 8].
- Program - A plan or scheme of action designed for the accomplishment of a definite objective which is specific as to the time-phasing of the work to be done and the means proposed for its accomplishment, particularly in quantitative terms, with respect to manpower, material, and facilities requirements. Provides the basis for budgeting [Ref. 5].
- Program years - The four fiscal years beyond the budget year [Ref. 5].





- Programming - The process of translating planned military force requirements into time-phased manpower and material resource requirements [Ref. 5].
- $R^2$  statistic - A statistic which represents the goodness of fit of the line provided by the regression procedure versus the observed occurrence [Ref. 11].
- RDT&E,N - An appropriation title: Research, Development, Test and Evaluation, Navy [Ref. 8].
- Reimbursable - An amount added to the total direct program which reflects the value of activity conducted in support of other governmental agencies or programs [Ref. 7].
- Reimbursements - When authorized by law, amounts collected for materials or services furnished to the public or other government agencies [Ref. 7].
- Selected Acquisition Report (SAR) - A report prepared for the Secretary of Defense which summarizes current estimates of technical, schedule, and cost performance of Navy development and procurement programs in comparison with original plans and the current program [Refs. 3 and 6].
- Serial correlation - The error terms from different observations are correlated; the effect of an error disturbance in one period carries over into another period. Synonym: autoregression [Refs. 10 and 12].
- Time-series data - Observations of the value of explanatory and dependent variables which are collected over time [Ref. 12].
- Total direct program - The total value of actions programmed in direct support of the budget activities making up an appropriation. Synonym: total obligational authority (TOA) [Ref. 8].



Total Obligational Authority (TOA) - The total amount of funds available for programming in a given year, regardless of the year the funds are appropriated, obligated, or expended. It includes new obligational authority, unprogrammed obligational authority from prior years, reimbursements not used for replacement of inventory in kind, advance funding for programs to be financed in the future, and unobligated balances transferred from other appropriations. Synonym: total direct program [Ref. 5].

WPN

- An appropriation title: Weapons Procurement, Navy [Ref. 8].



APPENDIX C - DATA TABLE (1000's) [Ref. 8]

<u>Category</u>	<u>FY62</u>	<u>FY63</u>	<u>FY64</u>	<u>FY65</u>	<u>FY66</u>	<u>FY67</u>
RDT&E,N (Current \$)	1318905	1503887	1565230	1423366	1582457	1947442
DOD Deflator	43.9582	44.3135	45.9732	46.1035	47.4930	49.1593
* RDT&E,N (Constant FY 79 \$)	3025136	3393745	3472640	3087327	3331979	3961493
Rounded Off (Millions)	3025	3394	3473	3087	3332	3961
PAMN/APN (Current \$)	3140241	3058029	2712071	2613309	3564360	3865306
DOD Deflator	45.9904	46.3855	47.2275	48.6782	50.3603	52.0849
* PAMN/APN (Constant FY 79 \$)	6828036	6592640	5742567	5368541	7077718	7421164
WPN (Current \$)						
DOD Deflator						
*WPN (Constant FY 79 \$)						
SCN (Current \$)	2590015	2635445	2088258	1815389	1875956	2175595
DOD Deflator	24.0430	25.1076	26.5571	28.7531	31.1050	33.8431
*SCN (Constant FY 79 \$)	10772429	10496603	7863276	6313716	6031043	6428474
OPN (Current \$)	870779	908992	1133771	1240797	2034167	2334469
DOD Deflator	45.9963	46.4283	47.2571	48.6736	50.3478	52.0919
*OPN (Constant FY 79 \$)	1893150	1957840	2399155	2549220	4040230	4481443
PMC (Current \$)	276835	265853	207598	168000	767600	542300
DOD Deflator	45.1000	45.7327	46.7602	48.2212	49.9034	51.6974
*PMC (Constant FY 79 \$)	613825	581319	443963	348394	1538172	1048989
TOTAL PROCUREMENT (Constant FY 79 \$)	20107440	19628402	16448961	14579871	18687163	19380070
ROUNDED OFF (Millions)	20107	19628	16449	14580	18687	19380

$$*(\text{Constant FY 79 \$}) = (\text{Current \$}) \div \text{DOD Deflator} \times 100$$



APPENDIX C - DATA TABLE (1000's) [Ref. 8]

Category	FY 68	FY 69	FY 70	FY 71	FY 72	FY 73
RDT&E,N (Current \$)	1886250	2191541	2271919	2212001	2411109	2541604
DOD Deflator	51.2022	53.7742	56.6423	59.4917	62.3895	66.1719
*RDT&E,N (Constant FY 79 \$)	3683924	4075451	4010994	3718167	3864607	3840911
Rounded Off (Millions)	3684	4075	4011	3718	3865	3841
PAMN/APN (Current \$)	3340538	3157066	2831030	3343064	3983000	3672509
DOD Deflator	53.9310	56.0717	58.4445	60.9120	63.9769	68.0851
*PAMN/APN (Constant FY 79 \$)	6194096	5630409	4843963	5488350	6225685	5393998
WPN (Current \$)						
DOD Deflator						
*WPN (Constant FY 79 \$)						
SCN (Current \$)	1231650	1070041	2464087	2356480	3010200	2962400
DOD Deflator	36.6967	39.6104	43.9544	49.5569	56.5394	62.9695
*SCN (Constant FY 79 \$)	3356296	2701414	5606008	4755100	5324075	4704500
OPN (Current \$)	2301149	2429227	1993190	1678011	1769889	2302170
DOD Deflator	53.9517	56.0621	58.4365	60.9538	64.0874	68.0960
*OPN (Constant FY 79 \$)	4265202	4333100	3410865	2752923	2761680	3380771
PMC (Current \$)	779900	645300	547200	249426	128100	182200
DOD Deflator	53.6040	55.7560	58.2066	61.0921	64.5106	68.7605
*PMC (Constant FY 79 \$)	1454929	1157364	940100	408279	198572	264978
TOTAL PROCUREMENTS (Constant FY 79 \$)	15270523	13822287	14800936	13404652	14510012	13744247
ROUNDED OFF (Millions)	15271	13822	14801	13405	14510	13744

$$*(\text{Constant FY 79 \$}) = (\text{Current \$}) \div \text{DOD Deflator} \times 100$$





APPENDIX C - DATA TABLE (1000's) [Ref. 8]

<u>Category</u>	<u>FY 74</u>	<u>FY 75</u>	<u>FY 76</u>	<u>FY 77</u>	<u>FY 78</u>	<u>FY 79</u>
RVP&E,N (Current \$)	2704473	3051614	3314320	3800055	4021791	4490500
DOD Deflator	72.0286	78.3905	83.0479	88.4412	94.2814	1.00000
*RVP&E,N (Constant FY 79 \$)	3754721	3892837	3990853	4296702	4265731	4490500
Rounded Off (Millions)	3755	3893	3991	4297	4266	4491
PAMN/APN (Current \$)	2936641	2777319	2977800	2931600	3552900	4078800
DOD Deflator	73.3651	78.2962	83.2543	89.6127	94.3985	1.00000
*PAMN/APN (Constant FY 79 \$)	4002777	3547195	3576752	3271411	3746224	4078800
WPN (Current \$)	806619	738700	1120500	2002300	2293300	2047500
DOD Deflator	73.0793	78.1249	83.1075	89.4623	94.7857	1.00000
*WPN (Constant FY 79 \$)	1103759	945537	1348354	2238149	2419458	2047500
SCN (Current \$)	3508400	3111400	3954181	5700400	5802500	4712400
DOD Deflator	69.6217	75.8109	81.3147	88.2123	93.9760	1.00000
*SCN (Constant FY 79 \$)	5039233	4104159	4862812	6462137	6174449	4712400
OPN (Current \$)	1375301	1569622	1837651	2198739	2186410	2708600
DOD Deflator	73.1864	78.1998	83.1819	89.5082	94.7841	1.00000
*OPN (Constant FY 79 \$)	1879176	2007194	2209196	2456467	2306727	2708600
PMC (Current \$)	207732	216100	279618	321674	450200	371900
DOD Deflator	73.6866	78.5933	83.4911	89.6990	94.8486	1.00000
*PMC (Constant FY 79 \$)	281913	274960	334908	358615	474651	371900
TOTAL PROCUREMENT (Constant FY 79 \$)	12306858	10879045	12331922	14786779	15121509	13919200
ROUNDED OFF (Millions)	12307	10879	12332	14787	15122	13919

\* (Constant FY 79 \$) = (Current \$) ÷ DOD Deflator x 100



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